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İNŞAAT MÜHENDİSLİĞİ
BİLDİRİLER KİTABI

9

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CIVIL ENGINEERING

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Investigation of the Effect of Blast Load on Static Parameters in Reinforced Concrete Structure Using Finite Element Method

Abdiladif Sadak Yusuf[1]

Abstract

This paper presents an investigation of the effect of the blast load static parameters in concrete structures by using the finite element method. This study was examined to determine the effect of the explosion on a five-story reinforced concrete structure by taking point nodes on every floor. A floor high is 3m and bay width is 5m and 4m respectively. The columns, beams, and slab dimensions were taken at 30°60cm, 30°50cm, and 15cm respectively. The concrete material was C30 as well. This study used blast acceleration data which is taken in the Samsun-Atakent quarrying blast. The study used a comparison method which is before and after the application of blast load on the structure and interpretation was made by paying attention to the most vulnerable on the floors. As a result of the study, the changes of moments, shear forces, displacements, and blast acceleration was given attention for comparing the before and after building's blast load. At the end of this study, explosive materials were evaluated for how effective and dangerous they are in concrete structures.

Keywords: blast load, reinforced concrete structure, finite element method, static analysis.

Introduction

In recent years, a structure exposed to blast load due to random events or natural events has gained importance and has become a serious issue that needs to be addressed quite often. This was given great attention due to incidents that occur accidentally or intentionally in buildings all over the world. Many structures and human lives in both developing and developed countries suffer from the blast loads. Attacking city centers with portable bombs has become one of the regular terrorist attacks worldwide [1]. When it comes to the explosion, it is not just that flames, clouds of smoke and irregular flying pieces, collapsed buildings, and very loud noises appear. In fact, the explosion is a combination of complex physical and chemical properties that kills

[1] Department of Civil Engineering, Ondokuz Mayıs University/Samsun, Turkey

valuable lives and collapses many buildings. Terrorist activities and threats have become a growing problem all over the world, and protecting citizens against terrorist acts include anticipating, preventing, and mitigating blast damages [2]. The effects of terrorist activities in city centers are neither limited to the target structure nor equivalent to the free space environment. The effects were devastating for the structure due to the channeling/funneling effect of adjacent structures [3]. In the past, structures were just designed to withstand normal load conditions and often could tolerate some abnormal loads, but the structures were not designed for blast load due to the low probability of explosion in the building and economic reasons, the structural members were not designed to respond elastically to a blast load and cannot resist the large magnitude of the blast load [4]. For this reason, it was started giving great attention to the problems of blast and earthquakes loads and their effect on the structures. The earthquake problem is quite old, but most of the information about it has been accumulated in the last fifty years [5]. Blast loading differs from ordinary loads (dead loads, live loads, snow, and wind) because the peak overpressure is very high and is applied to the structure for an extremely short time, and requires dynamic analysis [6]. . One of the main explosions that recently occur and use for terrorist attacks is Vehicle bombs that can deliver large enough explosives to cause potentially devastating structural damage [7]. The use of car bombs to attack urban centers has been a feature of campaigns by terrorist organizations around the world. A bomb explosion in or in the immediate vicinity of a building can cause catastrophic damage to the building's exterior and interior structural frameworks, the collapse of walls, blowing out through windows, and shutting down critical life safety systems [8]. Vehicle bombs can deliver large enough explosives to cause potentially devastating structural damage [9]. Another explosive attack threat is the hand-delivered small bomb [8]. Small arms can cause the most damage when brought into vulnerable, unsafe areas inside a building, such as the building lobby, mailroom, and retail areas. Loss of life and damage to building occupants, including direct blast effects, structural collapse, debris impact, fire, and smoke can be caused by the hand-delivered small bomb [10]. In a Ronan Point apartment tower in London in 1968, great emphasis is placed on the robustness of the structures, ie keeping the structures as insensitive as possible to local failures. In this fortuitous event, a gas explosion on the 18th floor of a high-rise prefabricated reinforced concrete building threw the walls out of the building and caused the support of the upper floor reinforced concrete slab to be lost. Structural failure, including glass breakage, resulted in many more victims and injuries than the blast wave itself. This loss

of support caused the corner of the entire building to collapse gradually, resulting in 5 deaths and 16 injuries [11]. Some problems were found in the design of the building, as well as some construction details of the joints, which led to a lack of structural redundancy; these observations led to changes in building codes [12]. Many buildings that can be loaded by explosive events are moment resisting frames in concrete or steel structures, and their behavior under blast loads is of great interest [13]. The explosion problem is relatively new, information on developments in this area is mostly provided through the publications of the Army Corps of Engineers, the Department of Defense, other government departments, and public agencies [13]. Eurocode EN 1991-1-7 refers to the case of accidental loadings and explosions, but mainly focuses on impact actions such as collisions from trucks, trains, ships, helicopters, or any other vehicle in general. Gas explosions occurring in confined spaces have also been referred to, but a general approach to design under non-explosive loads is still lacking [14]. This study was examined to determine the effect of the explosion on concrete structures and dynamic analysis was made with the finite element method. In addition, the effect of the explosion on a 5-story building by taking point nodes on every floor by comparing before and after the explosion on the building was analyzed and an interpretation was made by paying attention to the most vulnerable on the floors. The changes of moments, shear forces, displacements, and blast acceleration was given attention for comparing the before and after building's blast load. At the end of this study, explosive materials were evaluated for how effective and dangerous they are in concrete structures.

Materials and Method

Description of Explosion and Its Charge Profile

An explosion has been defined as a large-scale, rapid, and sudden release of energy. Explosions can be classified as physical, nuclear, or chemical events according to their nature. In physical explosions, energy can be released from the catastrophic failure of a compressed gas cylinder, from volcanic eruptions, or even from the mixing of two liquids at different temperatures [15]. In a nuclear explosion, energy is released from the formation of different atomic nuclei by the redistribution of protons and neutrons within the interacting nuclei, while the rapid oxidation of fuel elements (carbon and hydrogen atoms) is the main source of energy in chemical explosions. Explosives can be classified as solid, liquid, or gas according to their physical state.

Solid explosives are essentially high explosives for which their explosive effects are best known. It can be classified as a secondary or primary explosive according to its sensitivity to ignition. The second is an ignition in which simple ignition can easily explode from a spark, flame, or impact. Substances such as mercury fulminate and lead azide are primary explosives. Secondary explosives can cause extensive damage to the environment by creating blast waves when detonated. Examples include trinitrotoluene (TNT) and ANFO [16]. The explosion of a condensed high explosive produces hot gases at a pressure of up to 300 kilobar and at a temperature of about 3000-4000C° [17]. The hot gas expands and forces the volume it occupies. As a result, a layer of compressed air (blast wave) formed in front of this gas volume, which contained most of the energy released by the explosion. The blast wave instantly increased to a pressure value above the atmospheric pressure of the environment [18]. As this shock wave expanded outward from the blast source, it was termed side overpressure. After a short time, the pressure at the front may have dropped below the ambient pressure. In such an unfavorable stage, a partial vacuum is formed and sucked air. Accompanied by high suction winds that carried debris long distances away from the source of the explosion [19]. Figure 1, shows the shock wave velocity and blast pressure differences in explosive wave propagation.

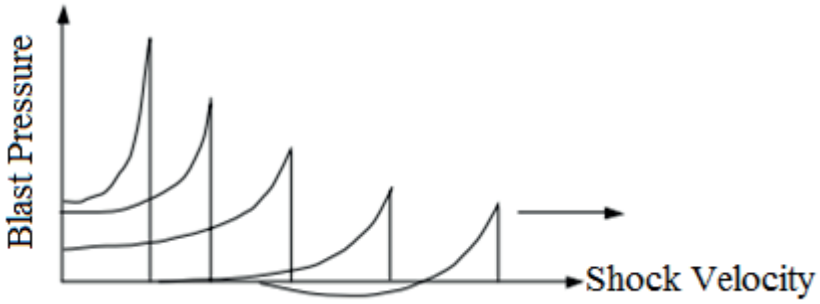

Figure 1. Explosive Wave Propagation (Ngo etal. 2007).

A blast wave passes through high explosives at a speed of 5,000–10,000 m/s. In a free air boundary, gaseous products expand at high speed, pressure, and temperature to produce a shock wave with an infinitesimal rise time, rapid fluctuations in air pressure, and produce a dynamic wind as they move from explosion air-gas mixtures, dust, and vapor clouds, It releases energy through a rapid combustion process known as a flare [16]. Figure 2 indicates the blast load profile in blast pressure, Stand-off distance, overpressure, and blast wave in between the vehicle and the structure. If the exterior building walls can withstand the blast load, the shock front can pass through window and door openings, protecting floors, ceilings, walls, contents, and people

from sudden pressures and shattered windows, doors, etc. Building components that cannot resist the blast wave will be broken and further fragmented and moved by the dynamic. The pressure immediately follows the shock front. Building contents and people will be displaced and rolled into blast wave propagation. This way, the explosion will spread throughout the building [17]. The analysis and design of structures subjected to blast loads require a detailed understanding of blast events and their effects on various structural members. Blast loads are actually dynamic loads that need to be carefully calculated, such as earthquake and wind loads.

Quarry Blasting

Quarry blasting is the controlled use of explosives and other methods such as pressurized gas blasting pyrotechnics to break up rocks. It is often used in mining, quarrying, and civil engineerings such as dams, tunnels or road construction. Blasting is one of the first operations carried out in a quarry to obtain the material to be processed. In the blasting part of this process, the chemical energy in the explosive is used to both break-up and displace the rock [18]. In quarries, blasting is done to break up large masses of rock and move the rock to where it can be loaded and hauled. Quarrying with explosives is an ancient and widely practiced activity and inherently has safety concerns. Standard practices used by mine operators have been developed that facilitate rock removal, reduce vibrations to surrounding structures, and increase safety[19]. This study was examined to determine the effect of the explosion on a five-story building by taking point nodes on every floor. A floor high is 3m and bay width is 5m and 4m respectively. The columns, beams, and slab dimensions were taken at 30*60cm, 30*50cm, and 15cm respectively. The concrete material was C30 as well. This study used blast acceleration data which is taken in the Samsun-Atakent quarrying blast. The study used a comparison method which is before and after the application of blast load on the structure and interpretation was made by paying attention to the most vulnerable on the floors. The 3D finite element model of the reinforced concrete structure was generated using SAP 2000 software.

Figure 2. 3D view of the Structural model.

Results And Discussion

It was carried out a static analysis of a reinforced concrete structure by applying a blast load to the structure using the finite element method. It's made a comparison of the loads before and after the application of blast load. This study was examined under collected blast acceleration data from Samsun Atakent quarry. From the structure, five-point nodes were taken which represent the five floors that the building contains. From every point nodes of the building were analyzed for their maximum moments, shear forces, and displacements in both cases before and after blast load and compared separately in both cases. Data was represented in both tables and figures as well.

Analysis of Reinforced Concrete Structure Before Blast Load

The results of the typical analysis before applying blast load to the reinforced concrete structure are shown in Table 1 and the shear forces, moments, and displacements respectively are given in Figures 6,7, and 8.

Table 1. Before blast load

Nodes	Moments (kNm)	Shear Force (kN)	Displacement (m) (10^{-6})
26	-1.1654	0.777	-0.29
27	0.0251	2.794	-0.52
28	-0.2111	3.137	-0.069
29	0.2006	3.177	-0.80
30	-1.4804	5.393	-0.86

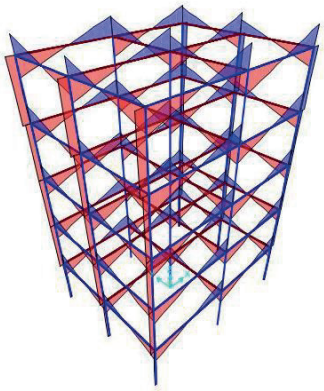

Figure 3. Shear forces before blast load.

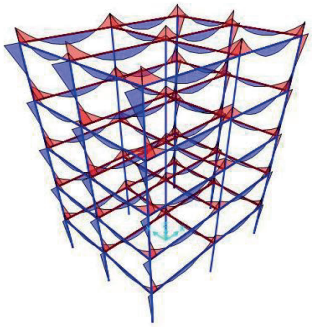

Figure 4. Moments before blast load.

Figure 5. Displacement before blast load.

Analysis of Reinforced Concrete Structure After Blast Load

The results of the typical analysis after applying blast load to the reinforced concrete structure are shown in Table 2 and the shear forces, moments, and displacements respectively are given in Figures 9,10, and 11.

Table 2. After blast load.

Nodes	Moments (kNm)	Shear Forces (kN)	Displacement (m) (10^{-6})
26	0.0154	0.006481	0.165
27	0.0016	0.006257	0.220
28	0.0014	0.005223	0.275
29	0.0010	0.007922	0.315
30	0.0008	0.008569	0.336

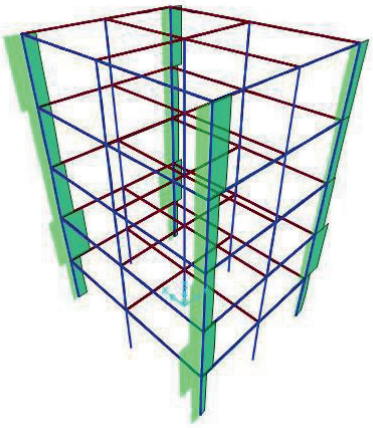

Figure 6. Shear forces after blast load.

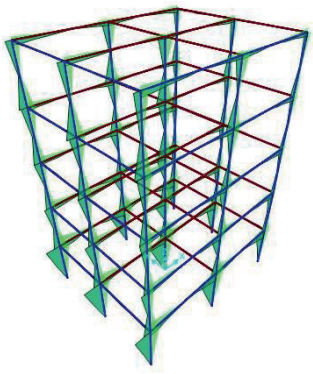

Figure 7. Moments after blast load.

Figure 8. Displacements after blast load.

Comparison of Analysis Results

The comparison of shear forces, moments, and displacements of the model before and after blast loads are given in Tables 3,4,5, and a figure for time acceleration as well.

Table 3. Shear forces comparison before and after applying blast loads.

Point of node	Difference (kN)	Difference (%)
26	0.7705	99.1659
27	2.7877	99.7761
28	3.1318	99.8335
29	3.1691	99.7506
30	5.3844	99.8411

Table 4. Moments comparison before and after applying blast loads.

Point of node	Difference (kNm)	Difference (%)
26	-1.1808	101.3214
27	0.0235	93.6255
28	-0.2125	100.6632
29	0.1996	99.5015
30	-1.4812	100.0560

Table 5. Displacements comparison before and after applying blast loads.

Point of node	Difference (m) (10^{-6})	Difference (%)
26	-0.29166	100.5721
27	-0.52120	100.4252
28	-0.69175	100.3997
29	-0.80415	100.3935
30	-0.85836	100.3930

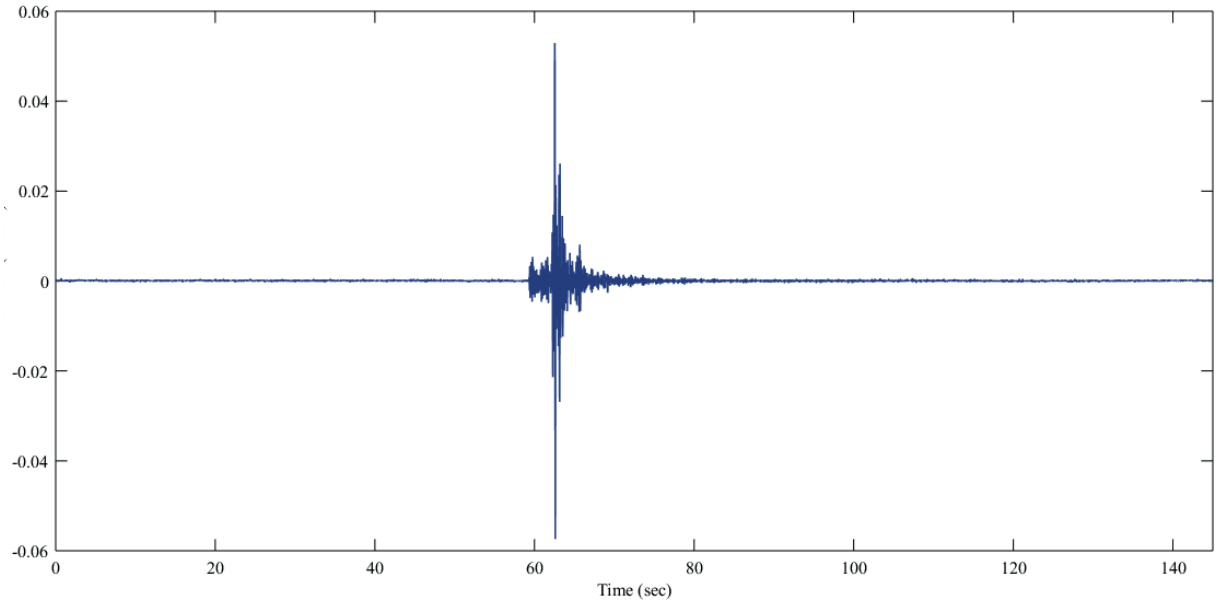

Figure 9. Time Acceleration.

Conclusions

In this paper, a static analysis of a reinforced concrete structure subjected to a blast load has been performed. The total duration of blast acceleration was 145.44 seconds and the maximum time with an acceleration of 0.0529 m/sec^2. The result of the structure analyzed before and blast load cases of shear forces, moments, and displacements, the ratio changes in the parameters of the structure are listed below:

In the node 26, the shear force, moment, and displacement differences between reinforced concrete structures before after blast load were obtained as:

The Shear force difference is 0.7705kN and the Percentage difference is 99.1659%.

The Moment difference is -1.1808kNm and the Percentage difference is 101.3214%.

The Displacement difference is -0.2917*(10^{-6})m and the percentage difference is 100.5721%.

In the node 27, the shear force, moment, and displacement differences between reinforced concrete structures before after blast load were obtained as:

The Shear force difference is 2.7877kN and the Percentage difference is 99.7761%.

The Moment difference is 0.0235kNm and the Percentage difference is 93.6255%.

The Displacement difference is -0.5212°(10^{-6})m and the percentage difference is 100.4252%.

In the node 28, the shear force, moment, and displacement differences between reinforced concrete structures before after blast load were obtained as:

The Shear force difference is 3.1318kN and the Percentage difference is 99.8335%.

The Moment difference is -0.2125kNm and the Percentage difference is 99.5015%.

The Displacement difference is -0.6918*(10^{-6})m and the percentage difference is 100.3997%.

In the node 29, the shear force, moment, and displacement differences between reinforced concrete structures before after blast load were obtained as:

The Shear force difference is 3.1691kN and the Percentage difference is 99.7506%.

The Moment difference is 0.1996kNm and the Percentage difference is 99.5015%.

The Displacement difference is -0.8041*(10^{-6})m and the percentage difference is 100.3935%.

In the node 30, the shear force, moment, and displacement differences between reinforced concrete structures before after blast load were obtained as:

The Shear force difference is 5.3844kN and the Percentage difference is 99.8411%.

The Moment difference is -1.4813Nm and the Percentage difference is 100.0560%.

The Displacement difference is -0.8584*(10^{-6})m and the percentage difference is 100.3930%.

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Bitişik Binalar için Rölatif Deplasman Tepki Spektrumlarının Oluşturulması ve Çarpışma Riskini Azaltmak için Viskoz Sönümleyici Tasarımı

Ahmed Ali Abdulqader Farhad [1]

Ersin Aydın [2]

Özet

Bitişik olarak inşa edilen ve aralarında yeterli boşluk bulunmayan binalar deprem esnasında birbirine çarparak ağır hasarlara neden olabilirler. Özelikle farklı fazlarda titreşen komşu binalar deprem esnasında birbirlerine yaklaşmaları durumunda çarpışma riski ortaya çıkacaktır. İki binanın çarpışmaması için en pratik yol aralarındaki boşluğun her iki binanın maksimum yatay deplasmanlarının mutlak değerinin toplamından daha büyük olarak seçilmesidir. Bitişik yapıların aralarındaki bu boşluğun belirlenmesi için kapsamlı çalışmalara ihtiyaç vardır. Bu çalışma, aynı yüksekliğe sahip bitişik iki yapının seçilen bir tasarım depremi altında tanımlanan rölatif deplasman spektrumlarının oluşturulması üzerine kurulmuştur. İki ayrı yapı beraberce modellenmiş ve iki serbestlik dereceli yapı modeli kurulmuştur. Yapılardan biri birincil, diğeri ikincil yapı olarak tanımlanmıştır. Birincil yapının periyodu ilk önce Tp=0.1s olarak alınmış ve diğer yapının periyodu geniş bir bantta değiştirilerek her küçük değişimde, El Centro (KG), Düzce (KG) ve Kobe (KG) deprem ivmeleri kullanılarak, zaman tanım alanında lineer analizler yapılmıştır. Sonra birincil yapının periyodu Tp=0.3s, 0.5s, 1s, 1.5s, 2s, 3s, 4s, 5s olarak alınmış ve analizler tekrarlanmıştır. Her bir artımda yapılan zaman tanım alanı hesabı sonucu bulunan en büyük rölatif deplasman değeri ile bitişik yapıların periyot oranları grafik haline getirilmiştir. Yapılan hesaplar, farklı sönüm oranları için tekrarlanmıştır. Bulunan rölatif deplasman tepki spektrumları, yapıların hangi periyot oranlarında çarpıma riskinin ortaya çıkabileceğini göstermektedir. Amaçlanan rölatif deplasman tepki spektrumları kullanılarak, yapılar arasındaki dinamik karakteristiklerdeki farklılıklar azaltılabilir. Bulunan bütün rölatif deplasman sonuçlarını kullanılarak iki 5 katlı bitişik yapı modelin aralarına viskoz sönümleyici çarpışma riskinin olduğu periyot oranlarına göre katlara eklenen sönümleyicileri dağılımlarının

[1] Niğde Ömer Halisdemir Üniversitesi, Fen Bilimleri Enstitüsü, İnşaat Mühendisliği Dalı.
[2] Prof. Dr., Niğde Ömer Halisdemir Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Dalı.

etkisi incelenmiştir. Her iki bitişik yapı modelin birinci periyotlarını kullanılarak optimum sönüm katsayılarını karşılaştırılmış ve etkinliği gösterilmiştir.

Anahtar Kelimeler: Bitişik yapılar, yapıların çarpışması, rölatif deplasman tepki spektrumları, optimum sönümleyici dağılımı, viskoz sönümleyiciler.

Disiplin: İnşaat Mühendisliği bölümü / Mekanik ve Yapı anabilim dalı.

Giriş

Özellikle arsaların değerli ve az olduğu büyük şehirlerde yapılar birbirine bitişik veya çok yakın inşaa edilmektedir. Bitişik nizam yapıların sahip oldukları farklı dinamik karakteristikleri nedeniyle deprem esnasındaki çarpışmaları çok sık görülen bir durumdur. Çekiçleme etkisi denilen bu etki, birbirine yakın yapıların dinamik karakteristiklerinin birbirlerinden farklı olduğu durumlarda, yapıların faz dışı davranışları neticesinde ortaya çıkmaktadır. Çarpışmadan dolayı yapılarda ciddi hasarlar veya yıkılmalar oluşmaktadır. Bunu engellemek için en basit yol yapıları birbirlerine yeter uzaklıkta inşa etmektir. Bu amaçla yapıları ayrı ayrı analiz edip, çarpışma riskini engelleyebilecek yapılar arası mesafeyi doğru tasarlamak gerekir. Genellikle, yapıların tepe deplasmanları arasındaki fark (rölatif deplasman) çarpışma problemlerinde kontrol parametresi olarak seçilmektedir. Deprem esnasında, bitişik yapılar arasındaki rölatif deplasmanın genliğinin artması çarpışma durumuna işaret eder.

Bitişik olarak inşa edilen fakat aralarında yeterli boşluk bulunmayan binalar deprem titreşimleri esnasında birbirine çarparak ağır hasarlara neden olabilir. Özelikle farklı fazlarda titreşen komşu binalar deprem esnasında birbirlerine yaklaşmaları durumunda çarpışma riski ortaya çıkacaktır.İki binanın çarpışmaması için en pratik yol aralarındaki boşluğun her iki binanın maksimum yatay deplasmanının mutlak değerinin toplamından daha büyük olmasıdır. Bitişik tarz binaların kat döşeme kotlarının farklı olması da çekiçleme etkisi sonucu ağır hasarlara neden olabilir.

Yapıların çarpışması probleminin analizi oldukça karmaşıktır. 330 göçmüş ya da ağır hasarlı yapı üzerinde yapılan hasar istatistikleri sonucunda yıkılmalar ve ağır hasarların en az yüzde 15 inin asıl sebebinin çarpışmalar olduğu görüldü [1]. Bitişik yapılar arasındaki çarpışma, problem analizini zorlaştıran karmaşık durumdur. Deprem esnasında bitişik yapılarda, yapısal reaksiyonu tanımlamak için çarpışmayla ilgili farklı analitik modeller geliştirildi [2]. Eşdeğer statik yatay kuvvetler altında komşu yapılar arasındaki mesafeyi belirlemek için potansiyel

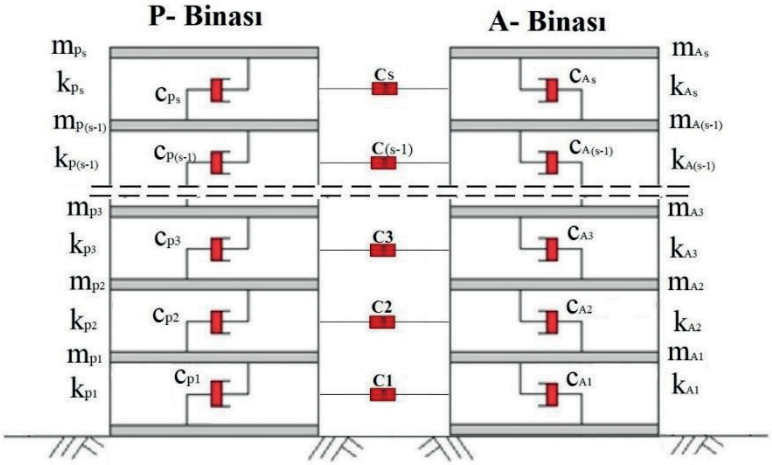
enerjiyi minimize ederek optimum koşullar elde edildi [3]. Yapılar arasında olan gerekli mesafeyi belirlemek ve çarpışmayı önlemek için spektral fark metodu ve çift fark kombinasyonu metoduna dayalı rastgele titreşim teorisi adı verilen bir metot önerildi [4]. Yer hareketinin kontrol performansındaki etkisi, sönümleyicilerin yerleri, sayıları araştırıldı [5]. Bitişik binalar problemlerde tek serbestlik dereceli sistemler olarak ele alınıp incelendi [6]. Spektrum yaklaşım üzerine, spektral fark yöntemi adı verilen yönteme dayalı bir yöntem önerildi [7]. Literatürde bitişik yapıların çarpışmasından kaynaklanan yapısal hasarlar hakkında çok sayıda rapor yayınlandı [8]. Ayırma mesafesi standart sapmasına göre bitişik binalarda çarpışmayı önlemek için rastgele titreşim teorisine dayalı, ortalama istatistiksel bir yöntem önerildi [9]. Çarpışmayı önlemek için çarpışma problemine dayalı sözde enerji uzunluğu üzerinde çalışmalar yapılıp minimum ayırma mesafesini hesaplandı ve farklı bir korunma tekniği kullanıldı [10]. Üniform dağıtılmış olan sönümleyiciler ile uygun aralıklarla bağlanılmış olan yüksek katlı binaların transfer fonksiyonu genliğini en aza indirmek için tepe deplasmanı hesaplandı [11]. Herhangi bir deprem kuvveti altında depreme verilen maksimum tepkiyi azaltmak için visko-elastik sönümleyicilerin optimum değerleri bulundu [12]. Olası çarpışmayı önlemek ve yapıdaki titreşimi azaltmak için bitişik yapıların her ikisine de eklenmiş olan ortak bir ayarlı kütle sönümleyicisi kullanıldı [13]. Çarpışmayı önlemek için pasif kontrol, aktif kontrol ve yarı aktif kontrol durumları için optimum üç kontrol stratejisi sunuldu [14]. İki bitişik yapıyı bağlamada kullanılan sıvı amortisörler için tanımlanan Maxwell modelinin en uygun parametrelerini bulmak için analitik formüller elde edildi [15]. Bitişik yapılar için bir aktif kontrol algoritması önerildi [16]. Pasif sönümleyicilerin etkilerini gösteren rölatif deplasman spektrumları sunuldu [17]. Bitişik yapılarda çarpışmayı önlemek amacı ile rölatif deplasman davranış spektrumlarını gösterildi [18]. Çarpmanın bitişik binalar üzerindeki etkisini önlemek veya hafifletmek için pasif sönümleyicilerden olan viskoz sönümleyicilerin uygulamaları araştırıldı [19]. Bitişik nizam iki yapı arasına, sönümleyiciler çarpışmayı önlemek için optimum olarak yerleştirildi. Optimizasyon problemi için yönetici denklemler zaman tanım alanında türetildi. Bitişik yapıların arasına lineer viskoz sönümleyicilerin uygun yerleri ve sayıları hesaplanmış ve onların yapısal davranış üzerindeki etkileri araştırıldı [20]. Deprem etkileri altında farklı dinamik özelliklere sahip bitişik yapıların çarpmasını önlemek için yapılar arasında viskoz sönümleyiciler için yeni bir optimal yerleştirme yöntemini araştırıldı [21]. Farklı deprem etkileri altında çarpışmaları önlemek için eşit olmayan yükseklikteki bitişik yapılar arasına yerleştirilen viskoz sönümleyicilerin optimum değerlerini araştırıldı [22].

Malzeme ve Yöntem

Bu çalışma, bitişik yapıların, seçilen bir depremi altında rölatif deplasman spektrumlarının oluşturulması üzerine kurulmuştur. İki ayrı yapı beraberce modellenmiş ve iki serbestlik dereceli yapı modeli kurulmuştur. Yapılardan biri birincil, diğeri ikincil yapı olarak tanımlanmıştır. Birincil yapının periyodu ilk önce Tp=0.1s olarak alınmış ve diğer yapının periyodu geniş bir bantta değiştirilerek her küçük değişimde, El Centro (KG), Düzce (KG) ve Kobe (KG) deprem ivmeleri kullanılarak, zaman tanım alanında lineer analizler yapılmıştır. Sonra birincil yapının periyodu Tp=0.3s, 0.5s, 1s, 1.5s, 2s, 3s, 4s, 5s olarak alınmış ve analizler tekrarlanmıştır. Her bir artımda yapılan zaman tanım alanı hesabı sonucu bulunan en büyük rölatif deplasman değeri ile bitişik yapıların periyot oranları grafik haline getirilmiştir. Yapılan hesaplar, farklı sönüm oranları için tekrarlanmıştır. Bulunan rölatif deplasman tepki spektrumları, yapıların hangi periyot oranlarında çarpıma riskinin ortaya çıkabileceğini göstermektedir. Amaçlanan rölatif deplasman tepki spektrumları kullanılarak, ya yapılar arasındaki dinamik karakteristiklerdeki farklılıklar azaltılabilir ya da aradaki mesafe uygun bir şekilde tasarlanabilir.

Bitişik Binalarda Sönümleyici Optimizasyonu

Aynı kat sayısına sahip ve aynı seviyede olan iki adet, rijit durumu için bitişik nizam kayma çerçeveleri göz önünde bulundurulacak olursa (Şekil 1) yapılar arasında akışkan viskoz sönümleyiciler ekleyerek çarpışmaları önlenebilir.



Şekil 1: Bitişik nizam yapılar ve sönümleyiciler

Yapısal sönüm matrisi $C=\alpha M$ şeklinde kütle ile orantılı olarak seçilmiştir. Sol (P) ve sağ (A)

yapının hareket denklemleri, denklem (1) ve (2) de gösterilmiştir.

$$M_P\ddot{U}_P(t) + C_P\dot{U}_P(t) + K_P U_P(t) = M_P r\ddot{U}_g(t) \quad (1)$$

$$M_A\ddot{U}_A(t) + C_A\dot{U}_A(t) + K_A U_A(t) = M_A r\ddot{U}_g(t) \quad (2)$$

Burada U deplasman vektörünü, $\dot{U}$ hız vektörünü, $\ddot{U}$ ivme vektörünü, $\ddot{U}_g$ yer ivmesi vektörünü göstermektedir. M, C ve K kütle, yapısal sönüm, rijitlik matrislerini, r ise deprem hareketi yönündeki serbestliklere karşı gelen elemanları bire eşit olan etki vektörünü gösterir.

P ve A yapının titreşimi beraber modellendiğinde hareketin denklemi aşağıdaki gibi yazılabilir.

$$M\ddot{U}(t) + C\dot{U}(t) + KU(t) = Mr\ddot{U}_g(t) \quad (3)$$

Burada,

$M = [M_P\ 0\ 0\ M_A\ ]$,

$$M = \begin{bmatrix} m1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ m2\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0 \\ m3\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ m4 \\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ m5\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0 \\ m6\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0 \\ m7\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0 \\ m8\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ m9\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ m10 \end{bmatrix} \quad (4)$$

$K = [K_P\ 0\ 0\ K_A\ ]$,

$$K = [k1 + k2\ -k2\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k2\ k2 + k3\ -k3\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k3\ k3 + k4\ -k4\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k4\ k4 + k5\ -k5\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k5\ k5\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ k6 + k7\ -k7\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k7\ k7 + k8\ -k8\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k8\ k8 + k9\ -k9\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k9\ k10 + k9\ -k10\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -k10\ k10\ ] \quad (5)$$

$C = [C_P\ 0\ 0\ C_A\ ]$,

$$C = [c1 + c2\ -c2\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c2\ c2 + c3\ -c3\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c3\ c3 + c4\ -c4\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c4\ c4 + c5\ -c5\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c5\ c5\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ c6 + c7\ -c7\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c7\ c7 + c8\ -c8\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c8\ c8 + c9\ -c9\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c9\ c10 + c9\ -c10\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ -c10\ c10\ ] \quad (6)$$

denklemler şeklinde verilmektedir.

Zaman tanım alanından frekans tanım alanına $\ddot{U}_g = \ddot{X}_g e^{i\omega t}$ ve $U = Xe^{i\omega t}$ bağıntıları kullanılarak dönüşüm yapılırsa, denklem 1 ve 2 dan

$$(K+i\omega C-\omega^2 M)X(\omega) = -Mr\ddot{X}_g(\omega) \quad (7)$$

formuna dönüştürülebilir. X(ω) ve $\ddot{X}_g(\omega)$; x ve $\ddot{x}_g$'nin Fourier dönüşümleri, ω zorlama frekansı, $i = \sqrt{-1}$ ifadelerini belirtmektedir.

$$(K+i\omega(C+C_{ad})-\omega^2 M)X_{ad}(\omega)=-Mr\,\ddot{X}_g(\omega) \quad (8)$$

şeklinde değiştirilebilir. Burada, $X_{ad}(\omega)$ viskoz sönümleyicilerin eklendiği durumda yerdeğiştirme vektörünün Fourier dönüşümünü ifade etmektedir. C_{ad} eklenen sönümleyicilere ait bilinmeyen sönüm matrisidir. Yeni bir parametre [23],

$$Y(\omega) \equiv \frac{X_{ad}(\omega)}{\ddot{X}_g(\omega)} \quad (9)$$

şeklinde tanımlanırsa, denklem (8) aşağıdaki gibi yazılabilir.

$$BY = -Mr \quad (10)$$

Y transfer fonksiyonuna karşı gelen yer değiştirme vektörü, B matrisi ise aşağıdaki gibi tanımlanmıştır.

$$B = K + i\omega(C + C_{ad}) - \omega^2 M \quad (11)$$

Burada, rijitlik K, kütle M, yapısal sönüm C ve $\omega=\omega_1$ olarak bilinmektedir. Tasarım değişkenleri, C_{ad} ile verilen matrisin içindeki c_{adi} sönüm katsayılarıdır. C_{ad} vektörlerin içeriği denklem 12' da verilmiştir.

$$C_{ad} = [cad_1\ 0\ 0\ 0\ 0\ -cad_1\ 0\ 0\ 0\ 0\ 0\ cad_2\ 0\ 0\ 0\ 0\ -cad_2\ 0\ 0\ 0\ 0\ 0\ cad_3\ 0\ 0\ 0\ 0\ -cad_3\ 0\ 0\ 0\ 0\ 0\ cad_4\ 0\ 0\ 0\ 0\ -cad_4\ 0\ 0\ 0\ 0\ 0\ cad_5\ 0\ 0\ 0\ 0\ -cad_5\ -cad_1\ 0\ 0\ 0\ 0\ cad_1\ 0\ 0\ 0\ 0\ 0\ -cad_2\ 0\ 0\ 0\ 0\ cad_2\ 0\ 0\ 0\ 0\ 0\ -cad_3\ 0\ 0\ 0\ 0\ cad_3\ 0\ 0\ 0\ 0\ 0\ -cad_4\ 0\ 0\ 0\ 0\ cad_4\ 0\ 0\ 0\ 0\ 0\ -cad_5\ 0\ 0\ 0\ 0\ cad_5\ ] \quad (12)$$

Denklem (10)'ten U transfer fonksiyonuna karşı gelen yer değiştirme vektörü çekilirse,

$$Y = -B^{-1}Mr \quad (13)$$

şeklinde olur. Burada, bilinmeyen c_{adi} ek sönümleyici parametreleri B vektörü içerisindedir. Tepe yer değiştirmesinin minimum yapılmak istenen transfer fonksiyonu değeri U vektörü içinde bulunmaktadır. Frekans alanında verilen bu denklemler kullanılarak iki binanın tepe noktasındaki rölatif deplasmanın transfer fonksiyonu değeri Lagrange Çarpanları Metodu kullanılarak optimumluk kriterleri türetilir. Ortaya çıkan doğrusal olmayan denklemler Steepest Step Direction Search Metodu ile çözülür[23].

Bulguların ve Sonuçların Tartışılması

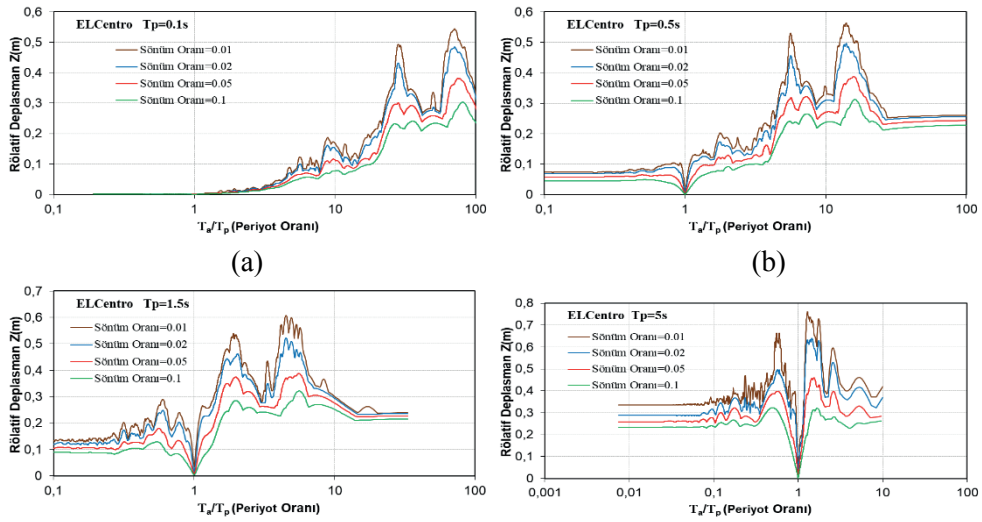
Bitişik Yapıların Rölatif Deplasman Tepki Spektrumlar Sonuçları

Çalışmada ele alınan bitişik nizam p ve a yapılarının modeli Şekil 1 de gösterilmiştir. Birinci

(p), ikinci (a) yapısını ifade eder. Yapılardan birinin titreşim periyodu önce sabit kabul edilerek, diğer yapının rijitliği geniş bir bantta değiştirilerek yapının titreşim periyodu küçük miktarlarda artırılmıştır. Her bir artımda iki yapının periyot ve frekans oranları değişmiş ve her artımda El Centro (KG) deprem ivmesi kullanılarak zaman tanım alanında hesap yapılmıştır. Zaman tanım alanında yapılan her bir hesapta yapılar arasındaki rölatif deplasmanın maksimum (pozitif işaretli) değeri bulunmuştur. Her bir periyot oranı için maksimum rölatif deplasmanların grafikleri çizilmiştir.

El Centro (KG) Deprem İvme Kaydı İçin Rölatif Deplasman Tepki Spektrumları

İlk olarak p yapısının periyodu 0.1s olarak seçilip farklı sönüm oranlarında, El Centro KG deprem ivmesi kullanılarak zaman tanım alanında hesap yapılmıştır. Diğer yapının (a) rijitliği değiştirilerek analiz yapılmış ve sonuçta yapıların periyot ve frekans oranlarına göre rölatif deplasman ile değişimi Şekil 2'da gösterilmiştir.



Şekil 2: Tp=0.1s, 0.5s, 1.5s ve 5.0s için rölatif deplasman tepki spektrumları (El Centro)

Şekil (2-a)'da birinci yapının periyodu 0.1 s olduğu zaman, bitişik yapılar arasındaki maksimum rölatif deplasman iki farklı periyot oranında pik değer yapmıştır. Periyot oranlarının yaklaşık 25-35 ve 65-80 olduğu durumlarda yapıların çarpışma riskinin olduğu söylenebilir. Yapıların periyot oranının 1 olduğu durumda ise maksimum rölatif deplasman sıfıra yaklaşır ki bu durumda yapılar aynı fazda titreşirler ve yapılar arasında çarpışma riskinin olmadığı söylenebilir.

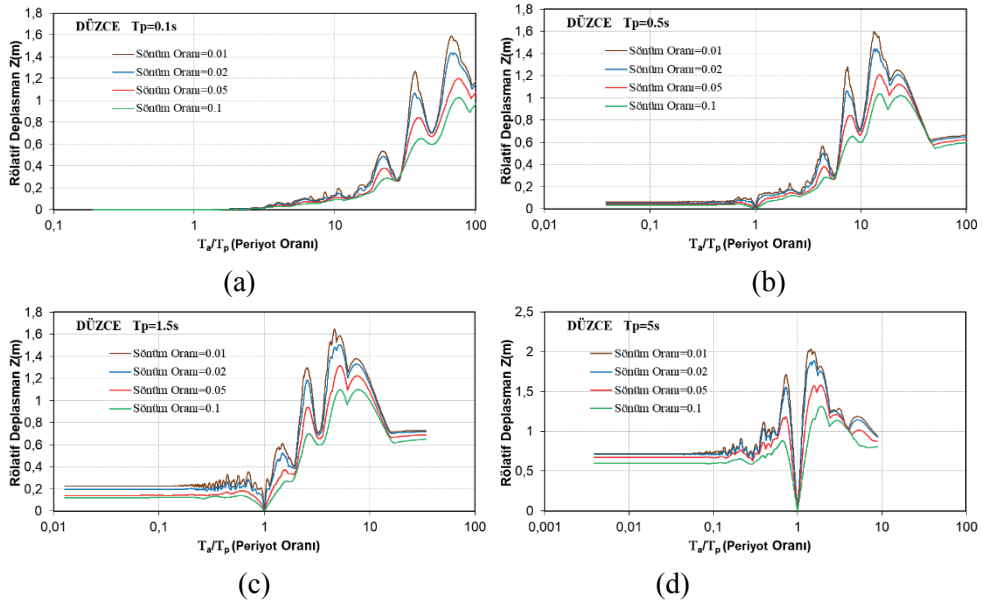
Tp = 0.5s, 1.5s ve 5s olması durumlarında, bitişik nizam yapıların çarpışma risklerinin

gerçekleşebileceği yaklaşık periyot oranları örnek olarak, Şekil 2'de görüleceği gibi farklı olmaktadır.

Düzce (KG) Deprem İvme Kaydı İçin Rölatif Deplasman Tepki Spektrumları

Yukarıda El Centro KG deprem ivme kaydı kullanılarak, rölatif deplasmanın periyot oranlarına bağlı olarak çizilen spektrumlarına ek olarak bu bölümde, aynı işlem Düzce KG deprem ivme kaydı kullanılarak yapılmıştır.

Şekil 3'te örnek olarak Tp = 0.1s, 0.5s, 1.5s, 5s periyotları için Düzce KG deprem ivmesi etkisinde rölatif deplasmanın periyot oranları ile değişimini göstermektedir.



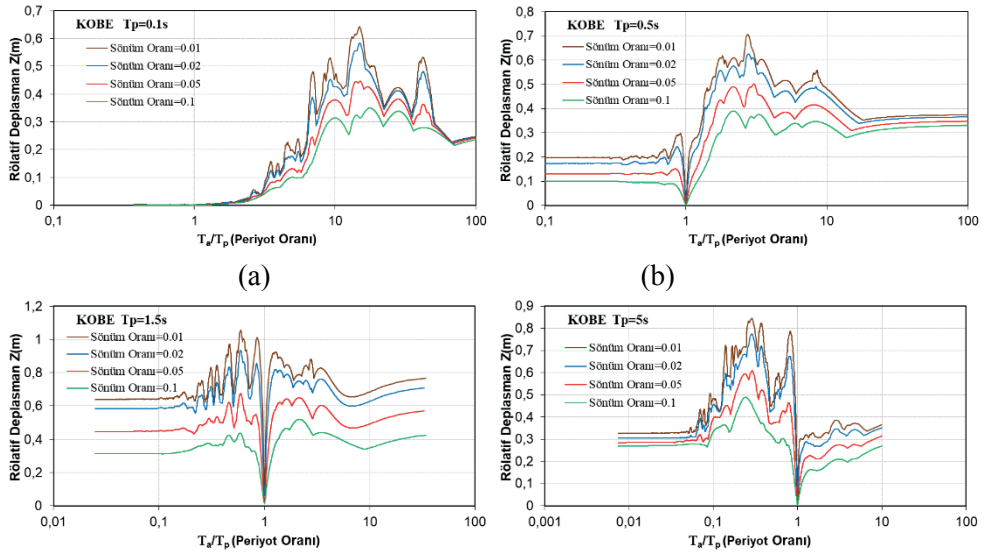
Şekil 3: Tp=0.1s, 0.5s, 1.5s ve 5.0s için rölatif deplasman tepki spektrumları (Düzce)

Şekil 3(a)'da ki grafiğe göre, Tp=0.1s için rölatif deplasmanın en büyük değerler aldığı üç adet uç notadaki periyot oranlarına bakıldığında yaklaşık olarak, 22.5, 39.5 ve 75.7 olduğu görülmektedir.

Kobe (KG) Deprem İvme Kaydı İçin Rölatif Deplasman Tepki Spektrumları

El Centro ve Düzce depremlerine ek olarak bu bölümde, aynı işlem Kobe deprem ivme kaydı kullanılarak yapılmıştır. Kobe depremi kullanılarak bulunan spektrumlarda çarpışma riskini gösteren periyot oranları, El Centro ve Düzce için çizilen spektrumlardaki periyot oranları ile karşılaştırılmaktır.

Şekil 4'te örnek olarak Tp = 0.1s, 0.5s, 1.5s, 5s periyotları için Kobe deprem ivmesi etkisinde rölatif deplasmanın periyot oranları ile değişimini göstermektedir.

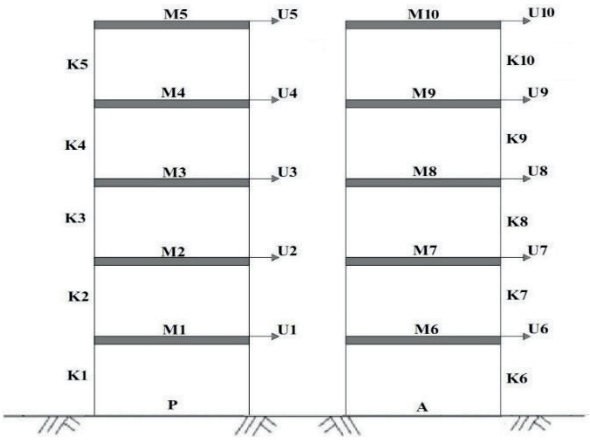


Şekil 4: Tp=0.1s, 0.5s, 1.5s ve 5.0s için rölatif deplasman tepki spektrumları (Kobe)

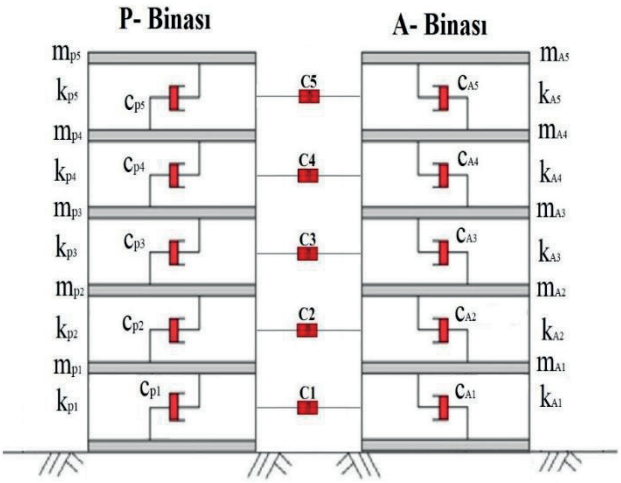
Şekil 4 (a)'da ki grafiğe göre, Tp=0.1s için rölatif deplasmanın en büyük değerler aldığı üç adet uç notadaki periyot oranlarına bakıldığında yaklaşık olarak, 4.98, 10.05 ve 15.09 olduğu görülmektedir.

Sayısal Örnek ve Sonuçları

Bitişik 5 katlı iki yapıda Şekil 16'da görüldüğü gibi deprem kuvveti etkisi altında ayrı ayrı kat deplasmanları meydana gelmektedir. Mathematica 5.0 (Wolfram Research, 2003) programı ile yapılan yazımlarda bu iki yapının sönümleyici olmadan (Şekil 5) ve her kat seviyesine yerleştirilen viskoz sönümleyiciler (Şekil 6) ile çözümleme yapıldı.



Şekil 5: 5-Katlı bitişik yapılarda serbestlikler



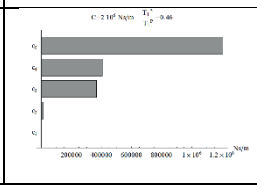
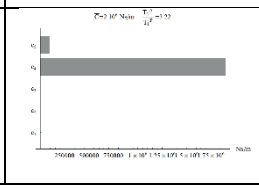
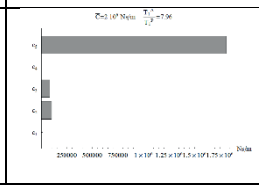
Şekil 6: 5-Katlı bitişik yapıların modeli

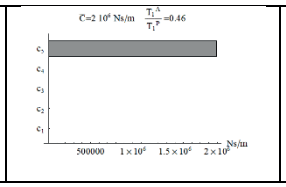
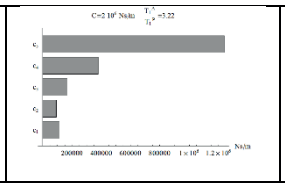
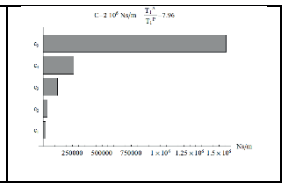
Bu çalışmada her kat için toplam kat kütlesi 75000 kg eşit değer verilmektedir. Katlara eklenen sönümleyicilerin toplam sönüm katsayısı $2\,x10^6$ Ns/m kullanılmaktadır. Bütün yapı modellerinde sönüm oranı sabit olarak 0,05 (5%) kullanılmaktadır.

Şekil 5. ve Şekil 6.'da gösterilen c_1, c_2, c_3, c_4, c_5 temsili sönümleyici görselleridir. Üç deprem datalarını kullanarak bulunan rölatif deplasman tepki spektrumlar sonuçlarından faydalanarak 5 katlı iki bitişik yapının analizi yapılmıştır. Sonuçlardan bir kısmi aşağıdaki bölümlerde verilmiştir.

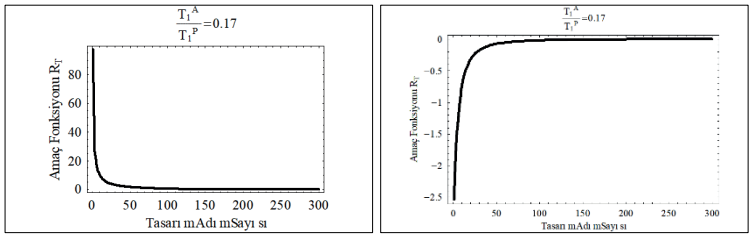
1.1.1. El Centro Depremden Rölatif Deplasman Tepki Spektrumları Kullanılarak 5 Katlı İki Bitişik Yapıların Analiz Sonuçları

Tablo 1: El Centro Depremi çarpışma riskinin olduğu yaklaşık periyot oranları Ta/Tp (Tp=1) göre Katlara eklenen sönümleyiciler-optimum sönüm katsayısı

El Centro (KG) Depremi Çarpışma riskinin olduğu yaklaşık periyot oranları Ta/Tp (Tp=1)		0,46	3,22	7,96
Katlara eklenen sönümleyicile r-optimum	1. Mo d			

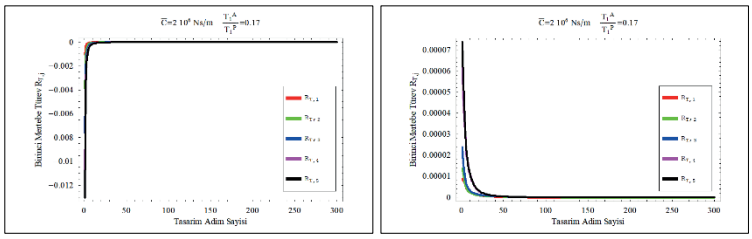
sönüm katsayısı Ns/m	2. Mod			

Aşağıda örnek olarak tasarım adım sayısına - amaç fonksiyonuna grafiği, tasarım adım sayısına - Birinci Mertebe Türev R_T grafiği ve tasarım adım sayısına - sönüm katsayısı grafiği verilmiştir.



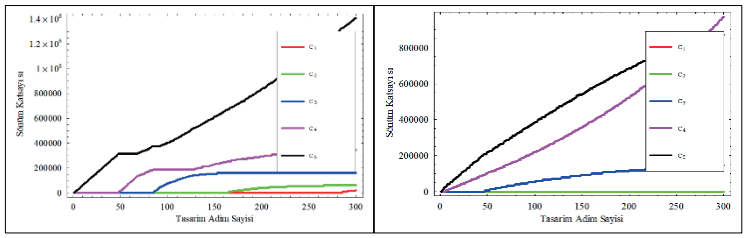
(a) (b)

Şekil 7: Tasarım adım sayısına - amaç fonksiyonuna grafiği (El Centro) a) 1. Mod. b) 2. Mod.



(a) (b)

Şekil 8: Tasarım adım sayısına - Birinci Mertebe Türev R_T grafiği (El Centro) a) 1. Mod. b) 2. Mod.



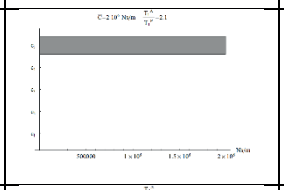
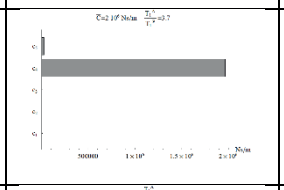
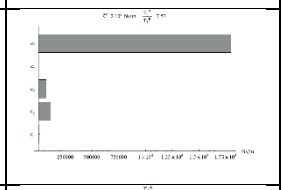
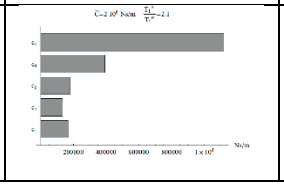
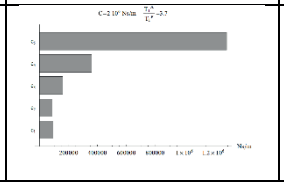
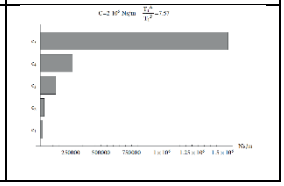
(a) (b)

Şekil 9: Tasarım adım sayısına - sönüm katsayısı grafiği (El Centro) a) 1. Mod. b) 2. Mod.

1.1.2. Düzce Depremden Rölatif Deplasman Tepki Spektrumları Kullanılarak 5 Katlı İki Bitişik Yapıların Analiz Sonuçları

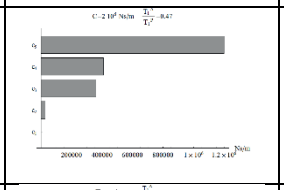
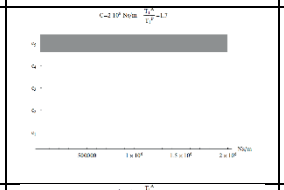
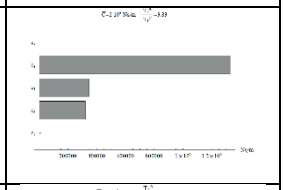
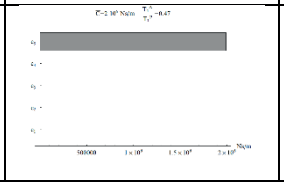
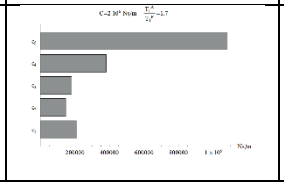
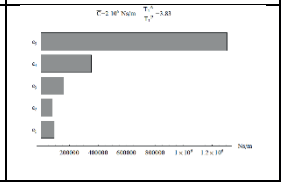
Tablo 2: Düzce Depremi çarpışma riskinin olduğu yaklaşık periyot oranları Ta/Tp (Tp=1) göre Katlara eklenen sönümleyiciler-optimum sönüm katsayısı

Düzce (KG) Depremi Çarpışma riskinin olduğu yaklaşık	2,1	3,7	7,57

periyot oranları Ta/Tp (Tp=1)				
Katlara eklenen sönümleyicile r-optimum sönüm katsayısı Ns/m	1. Mo d			
	2. Mo d			

1.1.3. Kobe Depremden Rölatif Deplasman Tepki Spektrumları Kullanılarak 5 Katlı İki Bitişik Yapıların Analiz Sonuçları

Tablo 3: Kobe Depremi çarpışma riskinin olduğu yaklaşık periyot oranları Ta/Tp (Tp=1) göre Katlara eklenen sönümleyiciler-optimum sönüm katsayısı

Kobe (KG) Depremi Çarpışma riskinin olduğu yaklaşık periyot oranları Ta/Tp (Tp=1)		0,47	1,7	3,83
Katlara eklenen sönümleyicile r-optimum sönüm katsayısı Ns/m	1. Mo d			
	2. Mo d			

Sonuçlar

Büyük ve kalabalık şehirlerde çok farklı dinamik özelliklere sahip yapıların birbirlerine çok yakın inşa edilmesi ile deprem esnasında ortaya çıkan çarpışma, depreme dayanıklı yapı tasarımı konusunda dikkate alınması gereken bir durum olarak ortaya çıkmaktadır. Bu çalışma yapıların çarpışma risklerinin incelemek amacıyla yapılmıştır.

Basit ve pratik bir yol olarak, seçilecek olan tasarım depremleri altında, yapıların çarpışma risklerinin hangi periyot oranlarında gerçekleşebileceğini, rölatif deplasman tasarım spektrumlarını kullanarak göstermektedir. Her biri tek serbestlik dereceli olarak tasarlanan yapıların deplasmanlarının farkı olarak alınan rölatif deplasman, bitişik yapıların çarpışmalarını önlemek amacı ile bir kontrol parametresi olarak kullanılmaktadır. Yapılardan birinin periyodu sabit tutularak diğer yapının periyodu, rijitlikteki küçük artımlar ile değiştirilmiş ve her bir küçük değişimde zaman tanım alanında hesaplar yapılmıştır. Önce sabit tutulan periyot değiştirilerek hesaplar tekrarlanmıştır. Farklı sönüm oranları için hesaplar yenilenmiştir. Yapılan hesaplar göstermiştir ki, bitişik yapıların periyotlarının artması çarpışma riskini artırmaktadır. Çizilen spektrumlar incelendiğinde, yüksek periyotlu bitişik yapıların titreşim periyotları arasındaki küçük farklar dahi çarpışma riskini ciddi derecede artırabilmektedir.

Bitişik veya birbirine yakın yapılmış yüksek katlı binaların sönümlü durumlarda dinamik davranışlarını incelemek amacıyla 5 katlı iki ana model oluşturulmuş, bu modeller üzerinde farklı analizler yapılmıştır. Sönümleyiciler viskoz sönümleyiciler olarak tasarlanmıştır. Bu analizlerden elde edilen sonuçlar aşağıda verilmiştir.

- Yapıların periyotları ve periyot oranları Ta/Tp farklı tepki göstermektedir. Yüksek periyot oranlarında genel olarak sönüm katsayısı üst ve tepe katlara etkilemektedir.
- Her iki yapının birinci moduna göre analiz yapılmıştır. Farklı özelliklere sahip olan iki aynı yükseklikte bitişik yapıların modlarına göre farklı tepki göstermektedir.

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Geopolimer Teknolojisinin Tarihsel Gelişimi, Geopolimerlerin Özellikleri ve Kullanım Alanları

Aigul Kabirova[1]

Mücteba Uysal[2]

Özet

Çalışmada, 1979 yılında Joseph Davidovits tarafından duyurulmuş olan geopolimerlerin, tarihine bir bakışın ardından, özellikleri ve kullanımı değerlendirilmiştir. Davidovits'in "Mineral polimerler ve üretim yöntemleri" başlıklı 1982 tarihli patenti ise, ilk geopolimer bağlayıcının icadı olarak gösterilir ve geopolimer biliminde ikinci kilometre taşı olarak kabul edilir. Bu tarihten itibaren geopolimerler üzerinde araştırmalar yapılmaktadır. Ancak geopolimer teknolojisinin tarihi pek eskilere dayanır. Davidovits tarafından herkesçe bilinen Antik Roma harcı ve betonlarında kullanılan çimentonun (Opus Signinum), günümüzdeki geopolimerik çimentolarda kullanılan metakaoline benzer kalsine kilin kireciyle alkali aktivasyonu sonucunda sertleşen yüksek performanslı bir malzeme olduğu ortaya konulmuştur. Davidovits ve diğer bilim insanları tarafından yapılan 2018 tarihli çalışma, Bolivya'nın Tiwanaku şehrinde bulunan Pumapunku kompleksini oluşturan anıt taşlarının antik insan yapımı geopolimer olduğunu göstermiştir. Bu çalışmada Antik Roma harcı ve betonları, Eski Mısır Krallığı'nın piramitleri ve mavi fayans çinileri, Paleolitik ve Etrüsk siyah seramikleri, Pumapunku anıt taşlarının geopolimer teknolojisini desteklediğini gösteren araştırmalar üzerinde durulmuştur.

Geopolimerler, günümüzdeki tanımlanmasına göre, alüminosilikatların alkali çözeltilerle kimyasal reaksiyonu (polikondenzasyon) sonucunda oluşan bağlayıcılardır. Geopolimer malzemeler, doğal kaynakların tasarruflu kullanılması, atık malzemelerin değerlendirilmesi, çok daha az karbondioksit emisyonu, daha yüksek mekanik özellikleri ve dayanıklılığı elde edilmesi açısından daha avantajlı yenilikçi bir yapı malzemesi olarak görülmektedir. Çalışmada, 1950'lerden bu yana geopolimer teknolojisinin kiriş gibi yapı elemanları, uçak pisti

[1] Dr., Karadeniz Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İnşaat Mühendisliği.
[2] Prof. Dr., Yıldız Teknik Üniversitesi, İnşaat Fakültesi, İnşaat Mühendisliği, Yapı Malzemeleri.

ve diğer uygulamalarda, tarihi eser restorasyonunda, kaplama ve boya malzemelerinin üretiminde kullanımına ilişkin bilgi verilmiştir.

Anahtar Kelimeler: Geopolimerler, Geopolimer Teknolojisi, Kadim Teknikler, Tarihi Eserler

Disiplin: İnşaat Mühendisliği

Giriş

Bildiride, geopolimer tenolojisininin tarihsel gelişimine bir bakışın ardından, özellikleri ve kullanımını değerlendirmek amaçlanmıştır. Geopolimerler, alüminosilikat malzemelerinin (örn. yüksek fırın cürufu, uçucu kül, alümina üretiminden meydana gelen kızıl çamur; kaolin, zeolit, bentonit üzerinde ısıl işlem uygulanmasıyla elde edilen metakaolin, metazeolit, metabentonit) alkali çözeltilerle kimyasal reaksiyonu (polikondenzasyon) sonucunda oluşan bağlayıcılardır.

Günümüzde mevcut çalışmalarda geopolimerlerin şu üstünlükleri olarak; kısa sürede dayanım kazanmaları, üretimi için gerekli olan malzemelerin kolayca bulunabilmesi, adhezyonunun herhangi bir yüzeye en iyi şekilde gerçekleşmesi, yüksek sıcaklığa ve korozyona dayanıklı olması şeklinde belirtilmiştir. Ayrıca, geopolimerler, üretiminde doğal kaynakların tasarruflu kullanılması ve atık malzemelerin değerlendirilmesi, çok daha az CO_2 emisyonu; daha yüksek mekanik ve dayanıklılık özellikleri elde edilmesi açısından daha avantajlı yenilikçi bir yapı malzemesi olarak görülmektedir.

Geopolimerlerin Tarihsel Gelişimi

Geopolimerler, Fransa'da 1970'li yıllarda organik plastik kullanımıyla ortaya çıkan yaygın hale gelen çeşitli felaket yangınları nedeniyle yanmaz malzemeler üzerine yapılan araştırmalar sonucunda, Davidovits tarafından duyurulmuştur. Davidovits (1979) tarafından dosyalanan "Mineral polimerler ve üretim yöntemleri" başlıklı 1982 tarihli ABD patenti ise, ilk geopolimer bağlayıcının icadı (poli(sialat) adı verilmiştir ve $M_n[(-Si-O_2)_z-Al-O_2-]_n$, wH_2O ampirik formülüne sahiptir) olarak gösterilir ve geopolimer biliminde ikinci kilometre taşı olarak kabul edilebilir [1].

Geopolimer Teknolojisini Destekleyen Mevcut Çalışmalar

Günümüzde; herkesçe bilinen Antik Roma harç ve betonları, Eski Mısır Krallığı'nın piramitleri

ve mavi fayans çinileri, Paleolitik ve Etrüsk siyah seramikleri, Tiwanaku/Pumapunku anıt taşlarının geopolimerler teknolojisini desteklediğini gösteren çalışmalar mecuttur.

Davidovits J. ve Davidovits F. [2], Antik Roma harç ve betonları üzerinde çalışmalar yapmıştır. Bu harç ve betonlarda başlıca Opus Signinum adıyla bilinen çimento kullanılmıştır. Opus Signinum, günümüzdeki geopolimerik çimentolarda kullanılan metakaolin/MK-750 (veya "kandoxi")'ye benzer kalsine kil (Latince "testa") kireciyle alkali aktivasyonu sonucunda sertleşen yüksek performanslı bir malzemedir ve özellikle sarnıç ve su kemerleri için kullanılmıştır. Vitruvius'un "De Architectura" eserine göre, harç ve betonlar için başka bir hammadde, "carbunculus" adındaki eşsiz bir jeolojik malzeme kullanılmıştır. "Carbunculus", yüksek sıcaklıkta (800ºC'de) işlenmiştir. Vitruvius, Vezüv Dağı (Pozzuoli) çevresindeki Napoli Körfezi'nden çıkarılan doğal puzzolanın özelliklerini, Roma'nın kuzeyinde bulunan Etruria'nın kalsine taşı olan "carbunculus"un özellikleriyle karşılaştırır. İkisi de beton yapılar için mükemmel malzeme olarak, ancak "carbunculus" karadaki yapılar için, doğal puzzolan ise deniz iskeleleri için daha uygun olarak değerlendirilir [2].

Davidovits [3], kayaç esaslı geopolimer çimentoyu, Roma çimentosu (Opus Signinum)'nu ve Ostia çimentosu (Opus Caementicum/Testacaem) ile, MÖ 2-3. yüzyıla tarihlenen arkeolojik örnekler üzerinde bir takım analiz yaparak, karşılaştırmıştır. Opus Signinum çimentosu, kayaç esaslı geopolimer çimentolarda kullanılan MK-750/"kandoxi"ye eşdeğer kalsine kaolinik kil olan "testa" ögesini ve karbonatlı kireci içermiştir. Opus Caementicum/Testacaem harcın içeriğinde, genellikle karbonatlı kireç, volkanik tüf agregaları ve İtalyanca "cretoni" olarak adlandırılan kum bulunmuştur. Bazı "cretoni"ler, kayaç esaslı geopolimer çimentolarda kullanılan kalsine volkanik tüflere eşdeğer "carbunculus" ögesi olduğu düşünülmektedir [3].

Davidovits [4, 5], antik Roma çimentosu ve Büyük Piramit bloklarının, geopolimerik reaksiyon (geosentez) sonucunda oluştuğuna, üzerlerinde kimyasal analiz, X-ışını analizi ve Nükleer manyetik rezonans (NMR) spektroskopisini yaparak, varmıştır [4, 5].

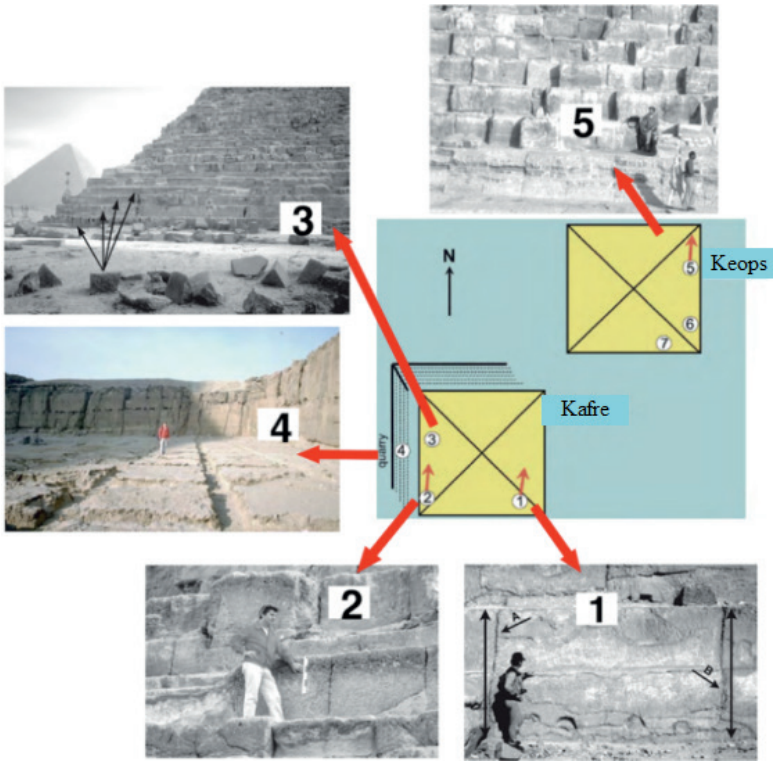
Davidovits [5] tarafından Eski Mısır Krallığı'nın başlıca piramitlerini oluşturan kalkerin insan yapımı taş olduğu hipotezi ortaya konulmuştur. Geleneksel olarak Turah ve Mokattam taş ocakları için ortak olan altı farklı sahadan örnekler alınmış ve üzerlerinde ince kesit analizi, X-ışını ve X-ışını kırınım (XRD) analizleri yapılmıştır. Sonuçlar, Keops, Teti ve Sneferu piramitlerinin kaplama taşlarıyla karşılaştırılmıştır. Taş ocağı örnekleri, %96-99 kalsit, %0.5-

2.5 kuvars ve çok az miktarlarda dolomit, alçı ve demir-alümina-silikattan oluşan saf kalker olarak bulunmuştur. Diğer taraftan, Keops ve Teti piramitlerinin kaplama taşlarının, %85-90 kalsit ve yüksek miktarlarda ocaklarda bulunmayan opal-CT, hidroksi apatit, silika alüminat gibi özel minerallerden oluşan kalker olduğu öğrenilmiştir. Piramit kaplama taşlarının yoğunluğu hafif olup, aynı yoğunluktaki taş ocağı örneklerinden farklı olarak, pek çok hapsedilmiş hava kabarcığı içermiştir. Davidovits [5], kaplama taşlarının doğal kalker olduğu durumda, piramitler bulunan sahalardan farklı olan taş ocaklarının bulunmadığını öne sürmektedir. Davidovits [5]'e göre, kırmızı kaplamalı bir taş kaplamanın XRD analizi, 4700 yıl önce Mısır'da komplike insan yapımı geopolimerik sistemin üretildiğini gösteren ilk kanıttır [5].

MacKenzie ve diğ. [6] tarafından Dahşur (Mısır)'daki Snefru'nun Bent Piramit (Eğri Piramit)'ine ait dış kaplama taşı ile bölgedeki iki taş ocağına ait kalkerlerin katı 29Si, 27Al ve 43Ca MAS NMR spektrumları karşılaştırılmıştır. NMR sonuçları, kaplama taşlarının Tura ocağından alınan ve insan yapımı amorf kalsiyum-silikat jeliyle çimentolaşmış olan kalker tanelerinden oluştuğunu göstermiştir. Taş yapımında ekstra silika kaynağı olarak Fayyum bölgesinin diyatomlu toprağı katıldığı tahmin edilmektedir [6].

Piramit kaplama taşlarının insan yapımı olup olmadığı konusunda paleomanyetizma çalışmaları yapılmıştır. Katılaşma sırasında taşlar, yoğunluk ve doğrultu yönünde, lokal manyetik alanı çeker. Bu alanın doğrultusu yaşa göre değişir. Eğer piramit blokları farklı manyetik yönelime sahip olursa, bunun nedeni, ocaklarından çıkarıldıktan sonra, rastgele bir şekilde birleştirilip kesilmeleridir. Diğer taraftan, bloklar aynı güney-kuzey manyetik yönelimine sahipse, katılaşmaları yerinde ve çok yakın bir jeolojik zamanda gerçekleştiği, dolayısıyla blokların yerinde insan tarafından (el yapımı) olduğu anlamına gelir. Túnyi ve El-Hemaly [7], yapay geopolimer kalker teorisinin geçerli olup olmadığını belirlemek için, Keops ve Kafre piramitlerinin taşları, karşılaştırma amaçlı da Mokattam ve Helvan taş ocaklarından alınan örnekler üzerinde paleomanyetik bir çalışma yapmıştır (Şekil 1). Çalışmanın bazı sonuçları aşağıdaki gibidir [7].

Şekil 1: Keops ve Kafre piramitlerinin taşları ile ilgili çalışmadan görseller



Kaynak: Geopolymer Institute, https://www.geopolymer.org/archaeology/pyramids/paleomagnetism-study-supports-pyramid-geopolymer-stone-2 (23 Eylül 2021)

Çalışmadan 3, 4 ve 7 nolu örneklerin Eosen devrimi kalkere ait olduğu tespit edilmiştir; 1, 2 ve 5 nolu örnekler güney-kuzey yönünde manyetik polarizasyona sahip olmuş, dolayısıyla insan tarafından yapıldığına varılmıştır; 6 nolu blok net bir şekilde belirlenememiş, hareket ettirilen tek bir geopolimer kalker olduğu tahmin edilmiştir; 5 nolu örnek için yönelim (kuzey-güney ekseni boyunca bir dönüş) görülmüştür [7, 8].

Davidovits, Sakkara'daki Basamaklı Djoser Piramidi'nin yeraltı galerilerini süsleyen ünlü mavi fayans çiniler gibi çini üretimi ile ilgili bildiri sunmuştur [4, 9].

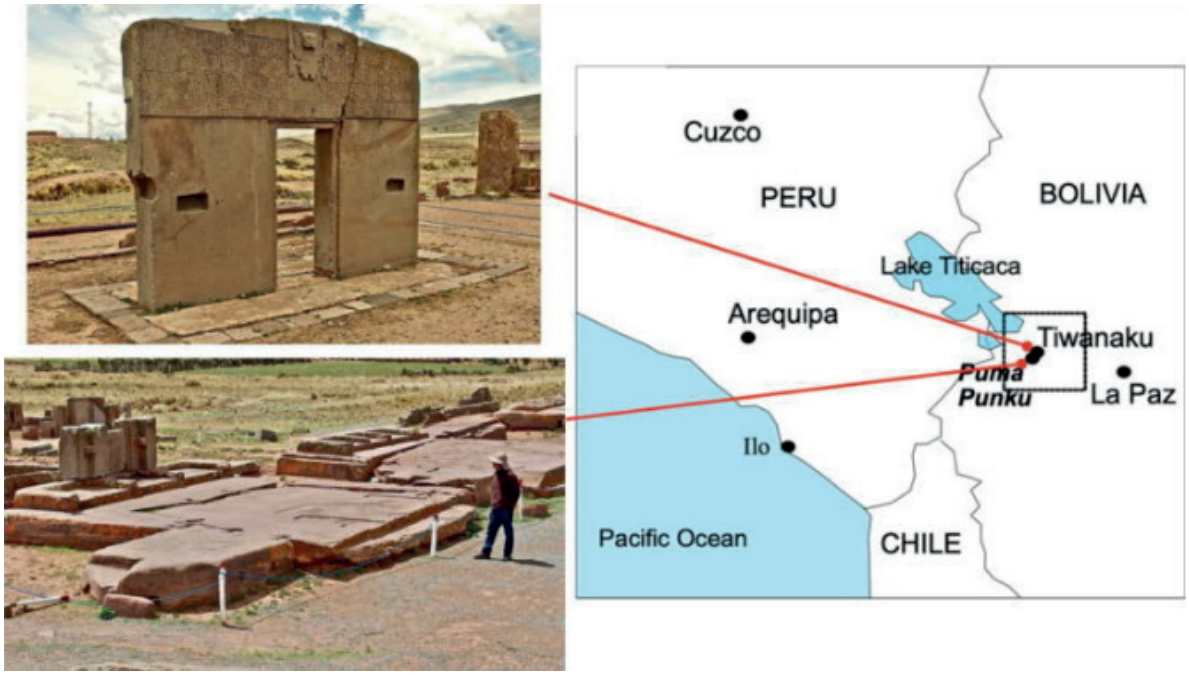
Sakkara'daki Djoser'in 3. hanedanına ait cenaze kompleksinde 30.000 mavi fayans çini bulunmuştur. Genel olarak çinilerin, 800-850ºC'de pişirme sırasında sırlanması sonucunda veya sıvı sırın içine daldırarak elde edildiği bilinir. Ancak, taramalı elektron mikroskobu (SEM) analizi, sırda fosfor varlığını göstermiş ve bu, firavun Djoser tarafından Sinai maden ocaklarında yoğun bir şekilde çıkartılmış ve bir alüminyum-bakır fosfat olan mavi mineral turkuazın (mafkatın) kullanılmasını düşündürmüştür. Davidovits, alüminyum fosfat hidrat ve bakır fosfat hidrattan yapılmış sentetik turkuaz (mafkat) karışımını içeren çözünebilir silikat bağlayıcıyla kendiliğinden sırlanma işlemini tekrarlamayı amaçlamıştır. Böylece, Davidovits

[9] tarafından, 250ºC'de Mısır fayansıyla aynı olan turkuaz mavisi renkli kendiliğinden sırlanan seramik elde edilmiştir. Daha yüksek sıcaklıkta, 350ºC'de, mavi renk, gri-siyah (mavi bakır fosfatın siyah tenorit (CuO)'e kimyasal dönüşümü sonucu), 800ºC'de ise yeniden mavi olmuştur. Çinilerin rengine göre, Djoser'in seramikçileri bu düşük sıcaklıktaki işlemi kullandıkları sonucuna varılmıştır. Bununla birlikte, pek çok Djoser çinilerinin mavi değil de Davidovits tarafından 250-350ºC'de kendiliğinden sırlanma işlemi sürecinde elde edilen gri, siyah, mavi-yeşil ve hatta kahverengi olduğu ortaya çıkmıştır [9].

Davidovits, seramiklerin düşük sıcaklıklarda (50-500°C) üretilebileceğini göstermiştir. LTGS (Low Temperature Geopolymeric Setting) olarak adlandırılan teknolojiyle, Paleolitik siyah seramik olan Dolni Vestonice Venüsü (MÖ 25.000)'nden, Bucchero Nero (MÖ 630) ve Impasto marrone (MÖ 650) Etrüsk siyah seramik çanak çömleklerinden görünüşte aynısını yapmıştır [10].

Davidovits ve diğ. [11] tarafından yapılan çalışma, Bolivya'nın Tiwanaku şehrindeki Pumapunku kompleksini oluşturan anıt taşlarının (Şekil 2) antik insan yapımı geopolimer olduğunu ve basit çekiç-taş, bilinmeyen teknolojiyle veya dünya dışı varlıklar tarafından oyulmadığını göstermektedir [11].

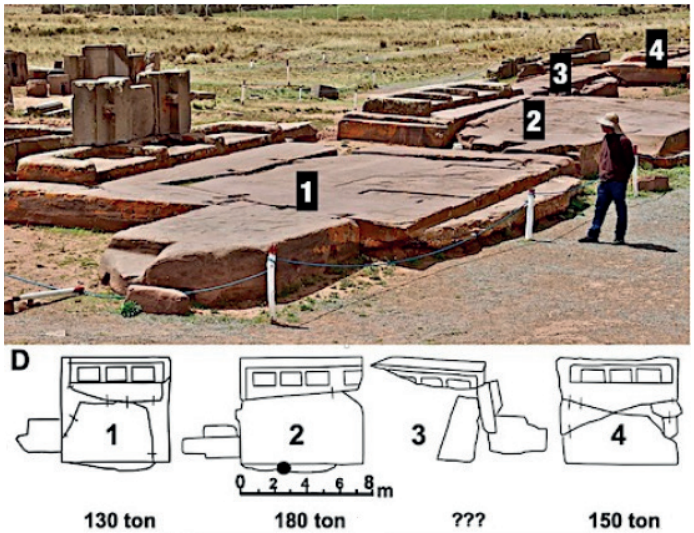
Şekil 2: Tiwanaku anıtlarının görünümü ve konumu



Kaynak: Geopolymer Institute, URL: https://www.geopolymer.org/archaeology/tiahuanaco-monuments-tiwanaku-pumapunku-bolivia (23 Eylül 2021)

Davidovits ve diğ. [12], optik mikroskop (ince kesit analizi), kimyasal (EDS), XRD ve SEM analizlerini yaparak blokların (bkz. Şekil 2) jeolojik kökenin öğrenmiştir. Pumapunku kırmızı kumtaşı anıtından alınan örneğin ince kesit analizi, kalın akışkan kırmızı ferro-sialat matrisli tane sınırlarını göstermiştir. Bu, jeolojik olarak oluşmuş kumtaşları için sıra dışı bir özelliktir ve yapay kumtaşı geopolimer beton fikrini destekler. Na, Mg, Al, Si, K, Ca ve Fe için yapılan SEM/EDS analizlerinin sonuçları, Pumapunku megalitik bloklarının kaynağı Kallamarka bölgesi (güneyinde, Kimsachata sıradağlarında bulunmaktadır) olduğunu düşündürmüştür. Şekil 3'te gösterildiği Pumapunku'nun ağırlığı 130-180 ton aralığındaki bu magalitik bloklar (döşemeler), Davidovits ve diğ. [12] göre, 1400 yıl önce dökülmüştür. Kumtaşı geopolimer betonun yapmak için, ince (hava etkilerine kalıp parçalanmış) kaolinitleşmiş kumtaşının Kallamarka bölgesinden getirildiği (bkz. Şekil 4) ve Salar de Uyuni'nin güneyinde bulunan küçük bir göl (Laguna Cachi, Altiplano-Bolivya)'den çıkarılan natron (Na2CO3) gibi yabancı ögeler eklendiği tahmin edilmektedir [12].

Şekil 3: Pumapunku'nun megalitik kırmızı kumtaşı blokları



Kaynak: Geopolymer Institute, URL: https://www.geopolymer.org/archaeology/tiahuanaco-monuments-tiwanaku-pumapunku-bolivia (23 Eylül 2021)

Şekil 4: Hava etkilerine kalıp parçalanmış, kolayca ayrışan kumtaşı katmanların görünümü

Kaynak: Geopolymer Institute, URL: https://www.geopolymer.org/archaeology/tiahuanaco-monuments-tiwanaku-pumapunku-bolivia (23 Eylül 2021)

Bununla birlikte, Davidovits ve diğ. [12] çalışması, Pumapunku bölgesinde bulunan daha küçük yapıların (Şekil 5) volkanik andezit taşından olup ıslak kumlu geopolimerin kalıba dökülmesiyle şekillendirildiğini göstermiştir. Bu gri andezitin SEM analizi ve optik ince kesit analizinden, organik maddenin varlığı görülmüştür. Davidovits ve diğ. [12] göre, bu organik madde geopolimer bağlayıcı olabilir [12].

Şekil 5: Pumapunku bölgesinde bulunan volkanik andezit taşı yapılar

Kaynak: Geopolymer Institute, URL: https://www.geopolymer.org/archaeology/tiahuanaco-monuments-tiwanaku-pumapunku-bolivia (23 Eylül 2021)

Davidovits ve diğ. [12] göre, volkanik bir taşın amorf organik madde içermesi çok olağandışıdır. Bu, yapay andezit geopolimer beton fikrini destekler; yapımı için de, Cerro Khapia sahasından kum kıvamındaki andezit taş malzeme olan konsolide edilmemiş volkanik tüf getirildiği ve yerel malzemelerle elde edilen organo-mineral geopolimer bağlayıcıyla karıştırıldığı tahmin edilmektedir [12].

Davidovits ve diğ. [12] çalışması, Pumapunku inşaatçılarının geopolimer beton üretiminin iki yöntemine ustalaştığını göstermiştir. Birincisi, günümüzde bilinen alkali ortamda (kırmızı kumtaşı megalitleri için). İkincisi de, asidik ortamda (gri andezit yapılar için). İkinci yöntem, yerel biyokütleden ekstrakte edilen organik karboksilik asitler ile birlikte guano kullanımına dayanır. Bu yöntemin geçerliliği Davidovits ve diğ. [12] tarafından test edilmiştir; laboratuvar ortamında modern kimyasallarla başarıyla tekrarlanmıştır [12].

Geopolimerlerin Özellikleri ve Kullanım Alanları

Geopolimerlerin Özellikleri

Mevcut araştırmalarda geopolimerlerin üstünlükleri; kısa sürede dayanım kazanmaları, üretimi için gerekli olan malzemelerin kolayca bulunabilmesi, adhezyonunun herhangi bir yüzeye en iyi şekilde gerçekleşmesi, yüksek sıcaklığa ve korozyona dayanıklı olması şeklinde belirtilmiştir. Tablo 1'de geopolimer harçların bazı mekanik özellikleri, geleneksel Portland çimentosu harcına kıyasla verilmektedir [14].

Tablo 1: Portland çimentosu harcı ve geopolimer harcının karşılaştırılması

Özellik	Portland çimentosu harcı	Geopolimer harcı
Basınç dayanımı, MPa	60	100
Eğilme dayanımı, MPa	5-6	10-15
Yoğunluk, g/cc	2.7	1.4
Optimum dayanım kazanma süresi, gün	28	1

Kaynak: W. Kriven, URL: www.youtube.com/watch?v=9kqAp9XrGWU (4 Temmuz 2021)

Geopolimerlerin Kullanım Alanları

Geopolimer malzemeler, fiziksel ve kimyasal özellikleri ile doğrudan beton yerine veya bir bağlayıcı (beton içerisinde çimentonun yerine) olarak prekast yapı endüstrisinde taşıyıcı ve taşıyıcı olmayan yapı elemanlarının üretimi, yol ve saha kaplaması, restorasyonu, zemin güçlendirilmesi, ağır iklim şartlarına ve yangına dayanıklı duvar kaplaması, heykelcilik, dekorasyon işleri, tarihi eser onarımları gibi sayısız sahada kullanılabilmektedir.

Günümüzde geopolimerleri yaygın olarak uygulayan ülke Avustralya'dır. Dünyada döşeme

sistemi elemanlarının üretiminde beton yerine geopolimer kullanılan ilk bina ise Queensland's Global Change Institute binasıdır (Şekil 6).

Şekil 6: Queensland's Global Change Institute binası

Kaynak: Architecture and Design, URL: www.architectureanddesign.com.au/news/uq-s-global-change-institute-is-first-to-use-cemen# (25 Ekim 2018)

Bu binanın döşeme sistemi, prekast geopolimer betondur. Elemanların betonunda Portland çimentosu yerine uçucu kül esaslı geopolimer kullanılmıştır (Şekil 7). Prekast geopolimer elemanların üretiminde, geleneksel prekast beton elemanlara göre daha az CO_2 meydana geldiği vurgulanmıştır [15].

Şekil 8: Queensland's Global Change Institute binasında geopolimer prekast beton döşeme elemanının montajı

Kaynak: Architecture and Design, URL: www.architectureanddesign.com.au/news/uq-s-global-change-institute-is-first-to-use-cemen# (25 Ekim 2018)

Avustralya'da 2014 yılında açılışı gerçekleşen Brisbane West Wellcamp Havalimanı'nın inşasında da geopolimer beton kullanılmıştır (Şekil 9). Bu havalimanının saha kaplamasında yaklaşık 40.000 m^3 (100.000 ton) geopolimer beton kullanılmıştır. Böylece, Wellcamp Havalimanı dünyanın en "yeşil" havalimanı olmuştur. Ayrıca, geopolimerin kullanılmasıyla 8.640 ton civarındaki CO_2 gazının doğaya salınımı engellendiği bildirilmiştir [16].

Şekil 9: Wellcamp Havalimanı'nın geopolimer saha kaplaması

Kaynak: Geopolymer Institute, URL: www.geopolymer.org/news/visit-airport-eco-building (25 Ekim 2018)

Avustralya'da WAGNERS şirketi uçucu kül-cüruf esaslı geopolimer betonu, ROCKWOOL şirketi ise, taşyünü atığı içerikli geopolimer tuğlalar üretmektedir [17].

Avrupa ülkelerinde halen geopolimerler, tamir harcı olarak başarılı bir şekilde kullanılmaktadır. Çeşitli ülkelerde geopolimer beton uygulamaları aşağıdaki gibidir:

- Avustralya'da, geopolimer beton lahit mezarları, geopolimer betonarme borular,

- Brezilya'da, Geopolimer bağlayıcıdan üretilen dekoratif mimari paneller,

- Fransa'da, geleneksel bir tuğlaya kıyasla üretimi için yaklaşık sekiz kat daha az enerji gerektiren, maliyet açısından üretimi daha ucuz, duvar için yeterli basınç dayanımına sahip ve suya daynıklı laterit toprak esaslı geopolimer tuğla,

- Fransa'da, otomotiv ve uçak endüstrileri için yüksek sıcaklığa dayanıklı geopolimer kompozit malzemeler,

- Almanya'da, geopolimer sıva harcı, dökümhaneler için geopolimer bağlayıcı, yangına

dayanıklı geopolimer boya, metalik ve mineral esaslı yüzeylerin korunması için asite dayanıklı sert antikorozif geopolimer kaplama,

- Çek Cumhuriyeti'nde, dökümhane maçaları için geopolimer kum bağlayıcı, dökümhaneler için geopolimer bağlayıcı,

- Hollanda'da, geopolimer dış cephe kaplamaları,

- Belçika'da, geopolimer LTGS tuğla,

- İrlanda'da, havacılık, rüzgar enerjisi santrali gibi sektörler için sıcak geopolimer kompozit aletler,

- ABD'de onarım/rehabilitasyon işlerinde kullanım için geopolimer harç sistemleri ve sıvı harçlar, su arıtımında kullanılan nano gözenekli geopolimer kompozitler, hafif ve yanmaz uygulamalar için geopolimer köpük çimento, aside dayanıklı uygulamalar için kuvarsit dolgu malzemeli geopolimer betonlar, kilden, pirinç kabuğundan, kireç ve cüruftan üretilen geopolimer bloklar,

- Kanada'da, maden ocağı atıklarından üretilen geopolimer beton,

- Çin'de, yanmaz geopolimer kompozit paneller,

- Rusya'da, yol inşaatı ve üç boyutlu yazıcı ile konut yapımı.

Tarihi Eser Restorasyonunda Geopolimer Harçların Kullanımı

Hanzlicek ve diğ. [13], Guiseppe Mario Mazza (1653-1741) heykelinin restorasyonunda bağlayıcı ve onarıcı malzeme olarak geopolimer harcının kullanılabileceğini göstermiştir (Şekil 10 ve Şekil 11).

Şekil 10: Guiseppe Mario Mazza heykelinin restore edilmiş hali

Kaynak: T. Hanzlicek ve diğ., URL: https://www.irsm.cas.cz/materialy/oddeleni/1/prezentace/Statue_2110.pdf (23 Eylül 2021)

Şekil 11: Guiseppe Mario Mazza heykeline ait iki terakota parçasının geopolimer harçla yapıştırılması

Kaynak: T. Hanzlicek ve diğ., URL: https://www.irsm.cas.cz/materialy/oddeleni/1/prezentace/Statue_2110.pdf (23 Eylül 2021)

Hanzlicek ve diğ. [13] tarafından yapılan başka bir çalışmada Adrspach Gate (Şekil 8) ve Delft Faience Sphinx (Şekil 12 ve Şekil 13) adlı tarihi eserlerin restorasyonunda geopolimer harcın kullanılabileceği kanıtlanmıştır.

Şekil 8. Adrspach Gate restorasyonu öncesinde ve sonrasında

(a) *(b)*

Kaynak: T. Hanzlicek ve diğ., URL: https://www.irsm.cas.cz/materialy/oddeleni/1/prezentace/Statue_2110.pdf (23 Eylül 2021)

Şekil 12: Delft Faience Sphinx eserinin orjinali

Kaynak: T. Hanzlicek ve diğ., URL: https://www.irsm.cas.cz/materialy/oddeleni/1/prezentace/Statue_2110.pdf (23 Eylül 2021)

Şekil 13: Delft Faience Sphinx restorasyonu öncesinde ve sonrasında

(a) *(b)*

Kaynak: T. Hanzlicek ve diğ., URL: https://www.irsm.cas.cz/materialy/oddeleni/1/prezentace/Statue_2110.pdf (23 Eylül 2021)

Sonuç

Bildiride; geopolimerlerin tarihsel gelişimi, özellikleri ve kullanımı ile ilgili bilgi verilmiştir. Günümüzde geopolimer malzemelerin geleneksel Portland çimentosu yerine başarılı bir şekilde çeşitli alanlarda kullanıldığı görülmüştür.

Geopolimerleri duyuran Joseph Davidovits ve Fransız, Yeni Zelanda, BK ve ABD üniversitelerinde araştırmalarını yapan bilim insanları bir takım analiz yaparak geopolimer teknolojisinin tarihi pek eskilere dayandığını göstermişlerdir. Bildiride; Antik Roma harç ve betonları, Eski Mısır Krallığı'nın piramitleri ve mavi fayans çinileri, Paleolitik ve Etrüsk siyah seramikleri, Tiwanaku/Pumapunku anıt taşlarının geopolimerler teknolojisini desteklediğini gösteren çalışmalar sunulmuştur.

Ayrıca bildiride; günümüzde, doğal kaynakların tasarruflu kullanılması, atık malzemelerin değerlendirilmesi, çok daha az CO_2 emisyonu, daha yüksek mekanik özellikleri ve dayanıklılığı elde edilmesi açısından daha avantajlı yenilikçi bir yapı malzemesi olarak görülen geopolimerlerin kiriş gibi yapı elemanları, uçak pisti, tarihi eser restorasyonunda, cephe kaplama ve boya malzemelerinin üretiminde kullanımına örnekler verilmiştir.

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A Systematic Study on Bangladesh's Construction Waste Management: Past, Present, and Future

Asmaul Husna Chara[1]

Nafisa Binte Farid Prova[2]

Nazmun Naher Rume[3]

Hodo Abdilahi[4]

Abstract

Bangladesh has recently experienced a considerable quantity of construction waste as an outcome of its rapidly developing building sector and economic expansion. Compared to other types of waste, a very few researches have been conducted regarding construction waste management problems. Construction waste management involves conducting the waste with proper treatment, recycling, reusing and minimizing the waste before landfilling. Different countries in the world apply different models but in Bangladesh no specific methods or implementation has been found. As urbanization and construction develop, the issue of construction waste has emerged as a new area of concern. Proper research and management plans are required to reduce this problem. According to the study, there has been no particular statistics on construction waste generation for years, as well as no effective legislation on construction waste management. This paper represents the past condition, present situation, practical implication and some actions for future construction waste management practices in Bangladesh. This study addresses the causes and sources of construction waste, sectors of using recycled materials and the state of construction waste generation and recycling in Bangladesh and other countries. It presents an overview of the existing construction waste management

[1] *Chittagong University of Engineering and Technology, Bangladesh, Department of Civil Engineering*

[2] *Islamic University of Technology, Bangladesh, Department of Civil and Environmental Engineering*

[3] *Leading University, Bangladesh, Department of Architecture*

[4] *Ondokuz Mayis University, Turkey, Department of Civil Engineering*

methods that have been studied so far. The scope of the study is to improve the construction waste management scenario of Bangladesh by analyzing SWOT (Strength, Weakness, Opportunities and Threat). This study will help the policymaker to choose the best criteria for the management of construction waste to achieve sustainable development and better environment for Bangladesh.

Keywords: Construction waste, Sustainable Development, Construction Waste Management, Bangladesh, Recycling.

Discipline: Science and Engineering

Introduction

Construction waste is defined as "any product, item, or element created as a result of construction work and abandoned, regardless of whether it has been processed or stockpiled before discarding" [1]. Construction Waste Management has gained attention due to increased waste production as a result of recent residential development [2]. Even though rapid urbanization and housing sector development complement each other, as they act as a critical driver of economic growth and a study proposes that economic growth policies should be focused on urban construction sector development [3]. But the generation of waste from this sector is the major obstacle in attaining sustainable construction. The construction industry is one of Bangladesh's promising sectors, accounting for approximately 80% of the total investment [4]. But this sector's waste concern continues to remain low. However, no on-site investigation has been undertaken to determine how much waste is formed from only construction waste and how to reduce it, as Bangladesh does not govern construction waste disposal. Although, research has only been performed in Dhaka so far anyway. The findings of the investigation indicated that the WGR for building and demolition operations was 63.74 kg/m^2 and 1615 kg/m^2, respectively [5]. But, according to [6], total waste stream data is available division wise where Dhaka, Chittagong, Khulna, Rajshahi, Barishal, and Sylhet contribute 69.7%, 17.1%, 6.7%, 2.2%, 1.6%, and 2.7% respectively. As a result, sufficient study, proposals, and applications are needed to define useful approaches to minimize construction waste generation and maintenance.

Bangladesh is a densely populated delta country congested with so many problems. Waste by construction is another big issue that has emerged. In building, components of Construction and

Demolition debris typically include brick, concrete, asphalt, wood, metals, etc. Brick is used as a material in making walls and concrete as coarse aggregate. Constructions of various sorts (both residential and non-residential) as well as roads and bridges are examples of structures. Being Bangladesh a least developed country, landfilling is not affordable in waste management [7]. In this situation, proper research is needed to mitigate construction waste generation and save the environment from further degradation. Research and technical resources for construction waste are minimal. There is an insufficiency of proper research on construction waste generation and its management in Bangladesh.

Many waste management strategies have been introduced to reduce the processing of construction waste. Reducing, reusing, and recycling waste and disposing of waste in landfills [8], [9]. Management strategies are based on two core principles: limiting resource use and reducing environmental emissions to build sustainability [8]. The main concern of all those concerned, as sustainable activities have not been prioritized in the past [10]. However, a study into the cost-benefit analysis of construction and demolition waste management is crucial to make a cost-effective decision to adopt the waste management practices [11]. Minimizing the waste generation rates is now a big concern.

This work aims to provide an overview of construction management in Bangladesh in the past, present, and future and identify the problems that cause Bangladesh to lag in Construction Waste Management, and find the best possible way. This study's objective is to improve the construction waste management scenario of Bangladesh by analyzing CWM (Construction Waste Management) models and SWOT (Strength, Weakness, Opportunities and Threat). This study will assist policymakers in choosing the best standards for managing construction waste to ensure that the environment in Bangladesh is free from pollution and gain sustainable development.

Methodology

In this systematic study, a research of viewpoints, problems, and concerns in developing the practice of construction waste management in Bangladesh was undertaken. This article discusses the literature review as a research method, as well as information gathered from various sources listed in the study when relevant. The goal of this article is to offer an outline of the research area and to examine its evolution through time. The assessment and analysis are

both qualitative studies.

A comprehensive analysis of SWOT (Strength, Weakness, Opportunities, and Threat) study was performed in order to implement appropriate construction waste management. As a result, Bangladesh will be able to define the goal of implementing efficient waste management on building sites. The approaches and implications for employing this management strategy and addressing the problems were illustrated.

Literature Review

Globally, construction and demolition waste disposal in 40 nations exceeded three billion tons per year until 2012, and this trajectory is accelerating [12]. It is estimated that the building sector has created trash with a residual value of more than 75 percent that is not currently utilized or recycled. The reason is attributed to the absence of an integrated waste management system [13]. For the previous several decades, the capital city of Bangladesh, Dhaka, has been residence to 30 percent of the country's urban population [14]. Meanwhile, as a consequence of the large influx of people, there is a growing demand for housing facilities, which has accelerated the building sector.

Bangladesh is now engaged in massive development projects which indicates many more are set to begin in the near future. In this perspective, waste creation might be massive. Consumers and clients in Bangladesh are rarely concerned about building waste management. As long as profit maximization and project completion on schedule are the primary goals, this waste might be considered an added burden [7]. Yearly construction waste statistics and study for different areas are still unavailable except for Dhaka city. According to [5], in the fiscal year (FY) 2016, Dhaka created around 1.28 million tons of garbage (0.149 construction and 1.139 demolition). Trash coming from construction is mostly a mix of left materials from new construction or demolition garbage. It might form as a result of excavation work, clearing any construction sites, highway construction, and rehabilitation or demolition of structures, along with other things. Concrete trash is easily combined with other types of garbage.

Several ideas and concepts are established in collaboration with professionals, activists, and scholars. They contributed to the introduction of the recycling hypothesis, such as 3R principle, 4R principle, 5R principle, and Zero Waste concept. The 3R strategy is focused on minimizing, reusing, and recycling, with reducing waste generation [15]. From a comparative study of

developing nations, it is found that these countries concentrated largely on waste disposal minimization [16]. After that, Bea Johnson introduced the Five R's in 2013 which follows the steps Rethink, Reduce, Recycle, Recovery and Reuse [17]. The zero waste concept includes more strategies than just 3R policy. In this concept the word 'waste' is replaced with the word 'resource' where 100% waste should be recycled and recovered for attaining a zero-waste city [18]. According to [19], building waste may occur at any stage of the construction process, with its sources in system design, construction practices, or even people's attitudes. The SWOT analysis has been adopted in the waste management sector to assess the strengths, weaknesses, threats, and opportunities in waste management strategies in various municipalities [20].

Various research demonstrates the classification on a different basis. According to [21], the causes of construction waste are organized into six categories which are design, procurement, and handling of material, operation, residual and disposal. The following table (Table 1) is a list of all of the group reports. This analysis is done by exemplifying them in order to make them clear to the readers.

Table 1: Classification of Construction waste

Base of Classification	Categories of Waste	Examples
According to the generation phase [22]	Construction	During construction phase
	Renovation	During remodeling or repairing of any structures
	Demolition	During the destruction of structures: Concrete, wood products, asphalt shingles, brick and clay tile, steel and dry wall.
According to the components [1]	Domestic	Paper, plastics, aluminum bottles etc.
	Inert	Brick, masonry, concrete, decoration materials etc.
	Non-inert	Bamboo, timber, paper, plastic, glass, packaging waste and other organic materials
	Chemical	Asbestos, lead paint, PCB caulking, lamp ballasts, mercury switches etc.
According to [23]	Structure	Concrete fragments, reinforcement bars, timber plates etc.
	Finishing	Surplus cement mortar, broken raw materials such as; mosaic, tiles, ceramics, paints etc.

According to the usability [24]	Reusable	Doors, windows etc.
	Recyclable	Steel, aluminum scrap, copper from wire etc.
	Mixed construction and demolition	Debris, bricks etc.
According to [25]	Physical	Material waste
	Non-physical	1. Time over-run, 2. Cost over-run
According to hazardous characteristics (Adapted from [26])	Hazardous	Concrete, bricks, tiles and ceramics in mixtures or alone containing hazardous substances, treated wood, glass, plastic (alone or in mixtures) containing hazardous substances
	Non-hazardous	•Wood-untreated •Glass-uncontaminated •Plastics-excluding packaging waste

Construction Waste Management (CWM) Models And Methods

Many kinds of research on construction waste management using various models have been conducted and adopted in other countries. The discovered models are accumulating in the table (Table 2).

Table 2: CWM models and methods

Model Name	Description
1. Circular Economy by [27]	• It is a regeneration concept focused on minimizing raw utilization.
2. Sustainable Construction Waste Management Implementation Model by [16]	• The framework contains four components: legislation, strategy, innovation, and guidelines. • Basically it is based on 4R principle.
3. Integrated management concept flowchart for CWM by [28]	• Four stages of waste disposal, namely waste reduction system, sorting system, raw material and energy recovery system and disposal system.
4. Green supply chain management practices (GSCM) by [29]	• Elements of GSCM - 1. Green Procurement (GP), 2.Green design (GD), 3. Green Manufacturing (GM), 4.Green Operations and Reverse Logistics (GO). • It enhances sustainability impact, eliminates waste, and maximizes potential savings.

5. MARKAL Model by [30]	• It is a technologically oriented model for goods and services demands.
6. WMMM by [10]	• Six projects are investigated and different waste handling procedures are found in different site management practices.
7. Construction waste process mapping by [31]	• Focused on the design phase. • Objective is to eliminate, reduce waste at every step in the design.
8. On-site sorting model by [11]	• A flow chart for on-site construction waste sorting process. • It includes the chemical waste which is negligible in the other models but is in the construction site.
9. WMP on-site sorting by [23]	• Separation of sources into different piles of 1. Inert, 2. Non-inert, 3. Recyclable, reusable and returnable materials. • Two different chutes have been used to separate inert and non-inert materials.
10. WMP Model by [32]	• This model is mainly consists of four elements; 1. Activity 2. Sorting element 3. Transport 4. Cost
11. CDW (Construction and Demolition Waste) flow chart by [8]	• This flow chart represents the hierarchy of resource use and environmental harm reduction. • It also includes a way for recycling such as jaw crushers, cone crushers.

This model's overview table will assist policymakers in selecting the best choice for implementation in Bangladesh.

Past and present situation of Construction Waste Management in Bangladesh

For better analysis of the management system in Bangladesh, the past and present scenario is separately presented below. Table 3 shows the past and present situation of Construction Management in Bangladesh.

Table 3: Past and present situation of Construction Management in Bangladesh

Past situation of Construction Management in Bangladesh	Present situation of Construction Management in Bangladesh
The management scenario in Bangladesh is always very poorly disregarded. In the past, the concern issue for construction waste management in Bangladesh was negligible. According to [7], solid waste generation and management statistics are still found and most of them are about the whole country or particularly about Dhaka city. Detailed construction waste generation and its management system for every district are not available.	• The current rate of single storied building has decreased from 72.8 percent to 7.9 percent since 1964 to 2007. According to Bangladesh National Building Code 2006, more construction of 8-12 storied buildings can be emerged as the areas are getting more Floor Area Ratio (FAR) [33]. • After the Rana Plaza disaster in 2013, significant changes have been noticeable. Some green building rating systems [33]: Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental design (LEED), Passive House Institute, Green Building Initiative, Energy Star, Living Building Challenge, One Planet Living etc. LEED is more focused in the design phase with waste source minimization. A proper waste management system for the construction site is still missing [33]. • According to [15], in 2009, Bangladesh, with the support of the Ministry of Environment of Japan and United Nations Centre for Regional Development (UNCRD) implemented the National 3R Strategy Development project. But sad part is that there is no specific policy or strategy regarding construction waste management for promoting 3R in Bangladesh. • In Bangladesh maximization of and completion of projects within due time is the main objective [7]. The management of construction waste is really a concerning part. But this is hardly seen in Bangladesh.

Scenario of Laws and Legislations for Construction Waste in Bangladesh

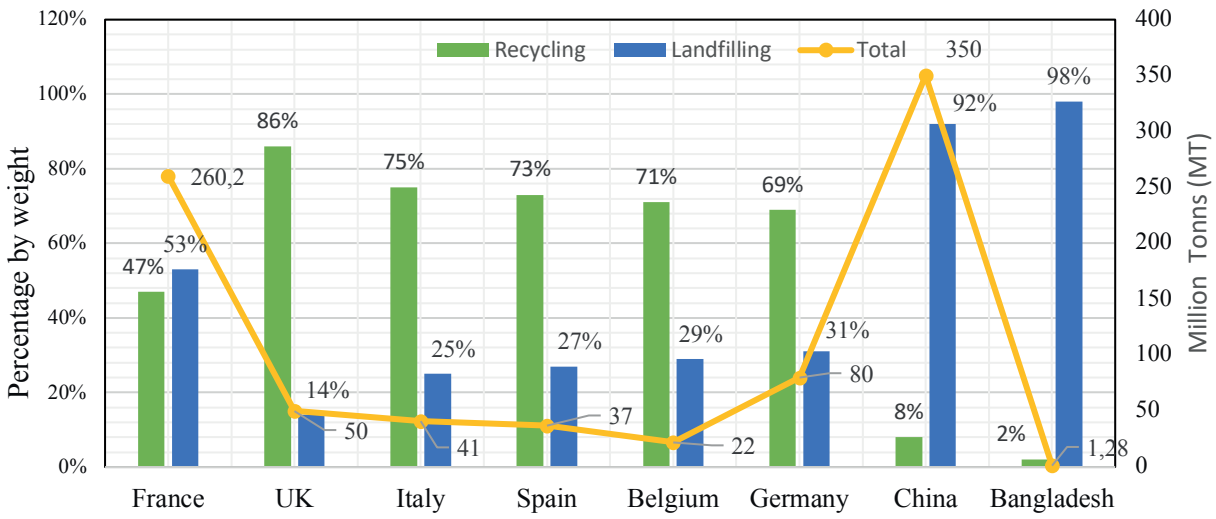
The framework of legislation for distinct 'Construction Waste' has not yet been defined or implemented in Bangladesh. However, some existing laws and legislations for overall waste management are National Environmental Management Action Plan (NEMAP), 1995, The Dhaka Municipal Ordinance 1983, The Environment Policy Act 1992, Urban Management Policy Statement 1998, Environment Conservation Rule 1997, The Penal Code, The Factory Act 1965, National Policy for Water Supply and Sanitation 1998 [6], [17] . If this study concentrates on these laws, it is found that NEMAP was created by the Ministry of Environment and Forestry (MoEF) to help with sanitation, solid waste management, supply of water, and environmental consciousness. Dhaka Municipal Ordinance authorizes the Dhaka City Corporation (DCC) to handle exclusively waste disposal in Dhaka, Environment Policy Act of 1992 primarily prohibits the discharge of municipal, commercial, or agricultural trash in any

water body. The Penal Code provides six months in jail or a Taka 2000 (BDT) fine, or both, for causing a public disturbance owing to dangerous chemicals. And the Factory act mostly manages industrial trash. So, this analysis of laws and legislation indicates that there are no specific adequate rules and legislation for construction waste management.

Construction Waste Management Comparison Of Bangladesh With Other Countries

The volume of construction and demolition waste produced by different countries is shown in Figure 1 in order to make the results comparable. This manuscript includes statistical data comparisons with other developed countries [17].

Figure 1: Comparison of Construction and Demolition Waste Generation and Recycling status



Recycling rates in EU countries are unquestionably higher than in China and Bangladesh, as shown in Figure 1. The total volume of the waste calculated in all EU Member countries is far lower than China's which exceeds 3500 MT. It is mostly due to mature schemes and long-term construction waste management experimentation. However, in Dhaka, construction waste is poorly handled, with an annual generation of about 1.28 MT of demolition waste, which is geologically insignificant. Among the mentioned countries here, the UK has the highest recycling rate which is 86% and Bangladesh has the lowest recycling rate of 2%.

Sectors of using Recycled Construction and Demolition Waste Materials in Bangladesh

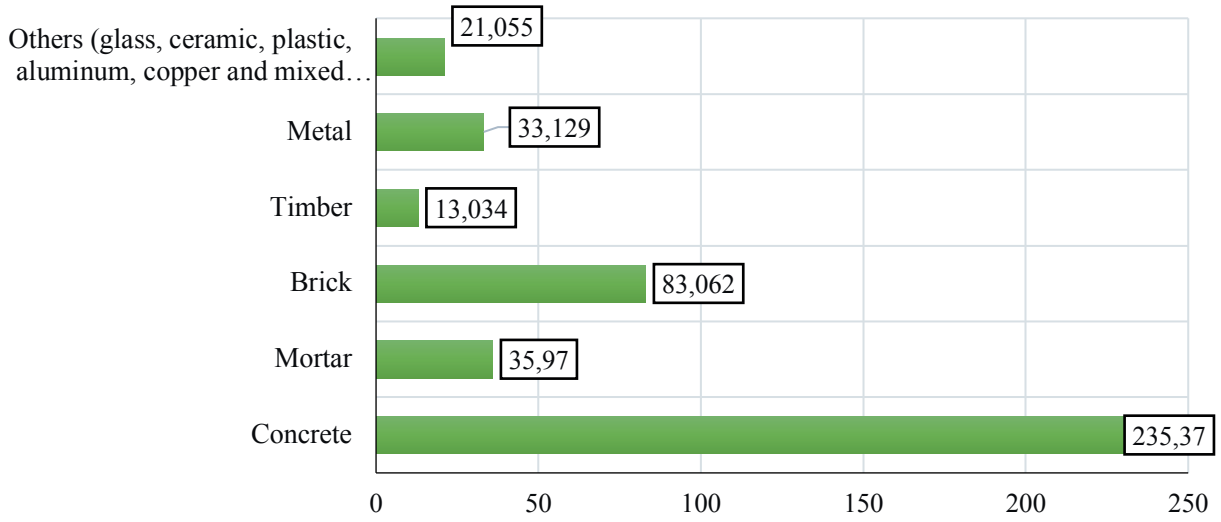
Prior studies did not specify the market prices of recycled items in Bangladesh. Due to the fact that concrete, brick/block, mortar, and other materials do not have any formed secondary market, they are dumped in unregulated locations [5]. An effective recycled market can be a suitable solution regarding this problem. The table (Table 4) represents the major distribution of construction waste materials and the sectors of using these recycled items which can be improved.

Table 4: Sectors of using Recycled Construction and Demolition Waste Materials in Bangladesh

Construction and Demolition Waste Materials	**Distribution (calculated by WGR method)**	**Probable Re-use of materials**
Concrete	60%	This waste can be recycled into aggregates for new concrete in 75 percent of cases with no negative impact on strength or workability.
Brick	21%	Broken bricks can be used to make blocks by combining them with cement and adhesive. Using broken bricks as a raw material replacement for brick manufacturing.
Mortar	9%	Crushed waste mortar can be used as a fine aggregate substitute in concrete, as well as in "green" concrete masonry blocks.
Timber	3%	This can often be reused as chipboard production and a substitution of coal.
Metal	3%	Distorted reinforcement bars are used by contractors and metal industries due to the high cost of metal.
Others	4%	Local factories, businesses, and small rural market shops are among the largest buyers of recycled household goods made from waste plastic and cardboard.

The data was obtained in a particular region, but no division-wise data all across Bangladesh was uncovered. The figure below (Figure 2) is a visual representation of Dhaka's construction waste rates in 2016 [5].

Figure 2: Construction waste generation rates in Dhaka city in 2016



	Concrete	Mortar	Brick	Timber	Metal	Others (glass, ceramic, plastic, aluminum, copper and mixed fragments)
Waste generation rate (kg/m2)	235,37	35,97	83,062	13,034	33,129	21,055

As seen in the graph above, the rate of concrete waste production is much greater than the average since it is extensively employed in construction work. So, if it can be reprocessed properly, a significant amount of waste may be reduced while also contributing market value.

SWOT on Construction Waste Management Analysis of Bangladesh

SWOT analysis has been used in the waste management community to recognize capabilities, vulnerabilities, risks, and opportunities in waste management strategies [20]. The table (Table 5) shows the SWOT on Construction Waste Management analysis regarding Bangladesh.

Table 5: SWOT Analysis of Bangladesh's Construction Waste Management [7], [14], [33], [34]

SWOT on Construction Waste Management in Bangladesh	**Positive**	**Negative**
	Strength	**Weakness**

Internal Influence	• The National 3R Strategy Development project. • Manpower of this densely populated country. • Existing green building rating systems. • Awareness among the concerned figures (researchers, PPP programs).	• Lack of specific regulation, guidelines and enforcement for construction waste management. • Being a densely populated country, Bangladesh cannot afford waste management by land filling. • There is no specific policy or strategy for promoting the National 3R Strategy Development project. • Shortage of finance and tax collection. • Improper partnership between public sectors, private sectors and community groups. • Insufficient research and technical resources related to construction waste management. • Absence of interest by the architects in waste minimization in the design phase. Because the design phase is considered as a major part where waste can be reduced [15]. • Unavailability of on-site sorting of construction waste. • Absence of effective recycling market.
	Opportunities	**Threats**
External Influence	• An effective possible recycle market. • Employment sector can be developed. • Contribution to Gross Domestic Product (GDP). • Attract foreign investors.	• Insufficiency of national policy to encourage waste management plan for the construction sector. • Shortage of suitable land for proper recycling • Unavailability of specific statistics about construction waste generation. • Absence of support and facilities.

Discussion

Proper construction of urban infrastructure is one of the significant factors which contributed to the generation of construction waste. The urban infrastructure model would not be adverse to the surroundings if it had proper waste management facilities. By finding the source of construction waste, reduction of waste can be achieved. As construction waste has become a significant barrier in achieving sustainable infrastructure, governments in developing countries have continued to strive to create ideas to solve the issues of construction waste. On the other

hand, in order to solve the issue of dumping system, a transformation in waste management policy should be implemented on a regular basis. The government agency is expected to launch the strategic implementation of waste management in the construction sector. This research investigated the scarcity of accurate data on Construction and Demolition waste production all over Bangladesh. The data was observed in a single district, but division-wise data from all over Bangladesh was not discovered. Finally, in order to effectively implement the Construction Waste Management system in Bangladesh, a SWOT analysis was conducted based on past and present situations, as well as relevant construction waste management information.

Future Investment and Idea

In a developing country like Bangladesh people are not aware enough about construction waste management properly. However, if this waste can be handled through the recycling procedure, then a new product will be developed. This waste material has the potential to become a new product on the market and can also contribute to a greater source of income. Furthermore, its market value will contribute to the country's GDP (Gross Domestic Product). Recycling the demolished material will help to achieve several Sustainable Development Goals (SDGs). So, from clients to field workers, literate to uneducated, public to authorities, must be aware of their involvement in achieving appropriate construction waste management.

Start-up Idea and 3D Model from construction waste

A waste can become aesthetically beautiful when we know how to use it properly. In construction waste management we found different types of waste materials around us such as: brick, concrete etc. These construction waste can be turned into a beautiful element in the interior design of houses. Construction waste brick can be used in a partition wall in the living room which will be environment friendly as well as cost effective also. The waste bricks may be elegantly used in interior walls, as shown by the SketchUp and V-Ray modeling below (Table 6) –

Table 6: Idea from waste brick (3D model view)

View of living space from dining space	View of dining space from living space
	

Recommendations

- Waste disposal, recycling, and reuse community outreach using public and social media;
- Laws and regulations must be specific for construction waste management;
- More research on potential waste material's reuse and market revaluation;
- Supervision of the total management system by the municipal authority of the respective city;
- Recycling and reuse policy should be adopted in the practice system;
- Field surveys can be an effective approach for the collaboration at different levels of construction starting from clients to field workers;
- Community outreach for construction waste disposal, recycling, and reuse through social media and public;
- Less disposal by minimizing waste production should be practiced. Emphasis has to be given to minimize waste production in the design phase by the architects. Using modern methods of construction can mitigate the construction waste;
- 3R, 4R and 5R can be the effective construction waste management strategy.

Conclusion

To conclude, a big concern related to the construction sector is generating construction waste. A sustainable construction process has gained a huge importance in the world of sustainable

development. With such a large consumption of materials for construction, this industry bears a significant obligation for contributing to attain sustainability. In Bangladesh, the unexpected feature is that there is no adequate data for waste produced by constructions as well as no specific regulations and legislation. No proper model has been implemented also. As the construction industry is expanding its outreach, the government should take Construction Waste Management into consideration as soon as possible since it is becoming more important due to ongoing research and practical experiences of those involved in this industry. The practices of Waste Management at Public-Private sector levels should be established in Bangladesh. By maintaining proper and effective coordination among policymakers, concerned authority and civil society, a successful implementation of Construction Waste Management in Bangladesh is surely possible. The concerned community and further research on how these materials might be utilized and regenerated should be developed.

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A Systematic Analysis on Adaptation of Modern Construction Using Advanced Technology: the Perspective to Bangladesh

Hodo Abdilahi[1]

Asmaul Husna Chara[2]

Nafisa Binte Farid Prova[3]

Nazmun Naher Rume[4]

Abstract

As a developing nation, in Bangladesh, construction industry is expanding at a rapid pace and building construction technology has not been developed yet to that extent level compared to other developing countries. Recently, Bangladesh has been involved in different mega projects as a lower middle income country. But most of the construction is based on labor-intensive, so the project time and work are not beneficial. Usage of modern machinery and techniques is thought to outperform production speed, protection, and efficiency. The use of technological advancement results a country to become fast forward and reduce the risk of human activities by replacing with technology. This study identifies the analysis of using the new advanced technology and its adaptation from the viewpoint of Bangladesh in civil engineering constructions. This study also shows that Bangladesh has already adopted the culture of using modern construction method in the building industry from the nineteenth to the twentieth centuries, but it doesn't develop the environment in using advanced technology. A systematic SWOT analysis and a questionnaire survey has been conducted by the civil engineers and construction professionals to better understand and to get an actual field scenario of construction sector in Bangladesh and how we can adopt this technique and tackle the challenges. The objective of this study is to help policymakers for bringing up modern advanced technology in the construction sector to make a fast, risk-free, eco-friendly Bangladesh and move Bangladesh from developing to a developed country.

[1] Ondokuz Mayis University, Turkey, Department of Civil Engineering
[2] Chittagong University of Engineering and Technology, Bangladesh, Department of Civil Engineering
[3] Islamic University of Technology, Bangladesh, Department of Civil and Environmental Engineering
[4] Leading University, Bangladesh, Department of Architecture

Keywords: Construction, Advanced Technology, Bangladesh, Labor-intensive, Machinery.

Discipline: Science and Engineering

Introduction

Bangladesh is a potential Least Developed Country (LDC) which is declared by the United Nations in 2021 with room to expand in terms of resources, the manpower, and security [1] .The construction industry sector has a substantial influence on a country's overall growth [2]. Production problems of operations, massive government restrictions, escalating prices, and social developments all led to an increase in infrastructure costs throughout the 1970s, resulting in a quest for innovative and inventive processes to assure quicker and more inexpensive development tracking [3]. Because the conventional design and construction were unable to handle the current difficulties, the entrepreneurs realized that they needed to get more active in the programs and projects of their initiatives [3].

The increase in engineering and building phasing has contributed to developing the Professional Construction Management (PCM) strategy [4]. This strategy draws together a team comprised of investors, developers, and building construction companies [4]. Level of efficiency and low productivity results in poor quality and higher-than-necessary pricing. Establishing institutions where the industry can gather together again to address problems and share knowledge is a crucial component of systems driven. There will be no development if the sector does not have participation [5]. Various international firms have successfully worked with Bangladesh firms and are now reaping their investment in Bangladesh and have been looking for a talented Bangladeshi human resource pool to undertake their computer-related works for an outsourcing base [6]. Danish International Development Agency (DANIDA) can assist the Bangladesh Association of Construction Industry (BACI) in facilitating the skills for Employment Investment Program (SEIP) to teach construction employees on occupational health and safety on worksites [6]. A real scenario of lean construction in Bangladesh is highlighted in a study [7].

The study's objective is to investigate the use of modern advanced technology and its adaptation in civil engineering works from the perspective of Bangladesh. This study also demonstrates that, from the nineteenth to the twentieth centuries, Bangladesh developed the culture of utilizing contemporary construction methods in the building sector, but it did not acknowledge

the infrastructure for applying advanced technology. A systematic SWOT (Strength, Weakness, Opportunities and Threat) analysis is done in order to know the challenges and issues of adapting advanced technologies in this sector. Based on the research findings, the study might assist construction organizations, researchers, and government agencies in directing their funds and support on the most important concerns. Moreover, the findings will benefit advanced economies, particularly those in South Asia with economic circumstances similar to Bangladesh.

Methodology

In this article, a study of perspectives, challenges, and issues in establishing advanced construction applying advanced technology in Bangladesh was conducted. This paper addresses literature review as a research approach, as well as facts collected from several resources cited in the paper where applicable. The purpose of this paper is to contribute an outline of the study field and analyze its growth through time. The evaluation and analysis are qualitative research.

The study has obtained its necessary data and information, mainly through questionnaires, to illustrate the negative and positive aspects of using modern construction technology perspective to Bangladesh. The questionnaires were conducted among the construction-related individuals such as researchers, engineers, project employees, etc.

For adapting advanced modern technology for the construction process, a structured SWOT (Strength, Weakness, Opportunities and Threat) analysis was conducted. As an outcome, Bangladesh would be able to establish the purpose of adapting technology in the building and construction industry and improving productivity and performance. Specific approaches for using this technology and dealing with the challenges were demonstrated.

Literature Review

The Indian subcontinent has pioneered the globe in the progress of construction technology and industry, as illustrated by the human civilization of The Indus Valley. However, some segments of the subcontinent, particularly Bangladesh, could not keep up with the latest technical advancements. Construction technologies may be categorized into three types depending on their operating and maintenance subject matter: equipment intensive, labor-intense, and labor-based technology [8].

In Bangladesh, the government has established the aim of developing infrastructure to achieve 'Vision2021.' As part of this goal, the Bangladesh government has committed 4,750,470,756 US dollar, or 40.32 percent of the 11,783,040,840 US dollar Annual Development Programme (ADP), to the development of sixty-one big and fast-track projects [9]. In these projects a crucial role can be played by the use of advanced technology. For example, In Japan, many construction robots or automated concrete finishers, steel welding machines, and facade inspection systems are employed on construction sites [10]. Advanced construction methods primarily involve manufacturing structures in factories, with possible benefits such as quicker construction, reduced infrastructure problems, and less energy consumption and loss and substantial ability to reduce waste production and safety issues in construction [11], [12], [13]. Also the use of advanced construction technologies is a possible strategy of achieving sustainable building [14].

Sustainable development must be supported by selecting the right technique of building and construction material within the sustainable design and management of construction. A delay evaluation demonstrates the impact of this faster approach on developmental projects [3].

In recent years, Bangladesh government has launched the construction of world-class development projects like the Padma Bridge, Rup-pur nuclear power plant, Matarbari power plants, Karnaphuli Tunnel, and Dhaka Metro Rail and the demand for highly modern infrastructure equipment has begun to rise [15]. However, the Bangladesh construction market covers the growing construction projects in different sectors such as Commercial, Residential, Industrial, Transportation and Energy and utility construction [16].

Construction related Design and Technology

Bangladesh implements technology for analysis and design at an acceptable level. Although most large enterprises analyze and design applying standard tools, a large number of engineers are still not acquainted with this technology [8]. Table 1 shows the software and technologies which are presently used in Bangladesh, indicating that Bangladesh is not lagging behind at the top level.

Table 1: Classification of Software and Tools

Types of Software and the Tools	Name of Software and Tools
Programming Language	Visual Basic, Auto LISP, Basic C, C++, Turbo C
Computer Aided Engineering	STAAD-III, STAAD-Pro, Math CAD, ADOSS, PCACOL, ETABS
Spread Sheet Analysis	Microsoft Excel, Lotus, Mathcad
Computer Aided Design	AutoCAD
Database	DBase, FoxPro, Microsoft Access, Oracle GIS Software, Arc/info, Arcade, MapInfo. Arc view, Idrisi32
Graphics software	CorelDraw, Harvard Graphics
Computer Aided Project Management	MS Project
Word Processing	Microsoft Word
Operating Systems	MS Windows, DOS, Novell

Availability of building Construction Equipment in Bangladesh

The most significant contributions to the construction of high-rise structures are undoubtedly done by Advanced Construction Technologies. Improvement in traditional methods such as slip forming have been made incrementally in recent years [17]. Specific technology, such as laser-based survey equipment, laser-guided excavation equipment, and new tunneling equipment, have seen dramatic advances [17]. It has been observed that construction techniques used in Bangladesh are still primitive and not usually scientific. Major cause behind this is the craftsman's lack of expertise and education [18]. Table 2 indicates the locations of some of the significant constructions and also which equipment is utilized in Bangladesh, as well as the nature of technology employed [8], [19].

Table 2: High rise and Recent Constructions location and Type of Technology used

High rise buildings and Recent Constructions	Location	Used Equipment	Type of Technology used
Karnaphuli Underwater Tunnel	Chittagong	Tunnel boring machine (TBM) acquired from China.	Equipment Intensive Technology
National assembly building	Dhaka	Tower crane, larger size mixture machines and other equipment replaced by huge no of	Labor based technology.

		labors.	
Bangladesh bank building	Dhaka	Hoist, mixture machine and other light equipment only. For excavation huge number of labors were engaged.	Labor based technology
Islamic Development Bank building	Dhaka	Tower crane, concrete pump, ready-mix concrete and other equipment replaced by most of the labors.	Equipment Intensive Technology
Bashundhara City building	Dhaka	Tower crane, concrete pump, ready-mix concrete and other equipment.	Equipment Intensive Technology

Considerable Advanced Construction Technologies for Bangladesh

Different studies have previously reported that approximately every stage of construction work in Bangladesh is conducted manually. Table 3 presents some of the Advanced Construction Technologies which can be taken into consideration for adapting in the construction sector of Bangladesh.

Table 3: Considerable Advanced Construction Technologies for Bangladesh

Advanced Construction Technologies	Description
Building Information Modeling (BIM) Technology	• The capacity to collect information in a centralized location, namely the Building Information Modeling (BIM) model [20]. • Another benefit, it has the ability to rapidly and easily inspect the geometry and information contained in the model [20]. • Korea and Hong Kong are emerging as regional leaders, while China and Japan have strong official support for BIM implementation. Despite these four strong leaders, the degree of adoption on the continent must be considered poor [20].
PCM (Professional Construction Management)	• This approach is to help minimize project durations and satisfy overall project objectives [3]. • It allows the owner to fully engage in the construction process [3].

Lean Construction	• The Lean approach has resulted in significant and long-term increase in efficiency, quality, waste disposal etc. [7]. • By eliminating waste and ensuring the excellence of construction products, this strategy maximizes the product value to clients [21]. • It has a substantial impact on increasing project performance and speeding up the construction timetable [22]. • In a pilot project in Sweden, Eriksson used lean construction techniques and discovered some major benefits [23]. • Barriers to this method in the Singaporean construction sector include a lack of readiness to provide training and resources, a reluctance to adopt new systems, processes, and innovation, and an inclination to maintain the organization's and people's culture [24], [25]. Similar challenges are faced to implement lean construction in India [26].
Modular Construction	• Modular technologies are widely employed in low-rise buildings for a variety of purposes, including office and residential buildings, warehouses, sanitary and special-purpose facilities, and so on. They have, however, been used in multi-story and even high-rise construction in recent years [27]. • Being an energy-saving construction technology, it reduces the cost of construction and material resources [27].
Mivan Technology	• A Malaysian corporation established the Mivan Technology System in the late 1990s as a productive method for building mass housing estates in developing nations [28]. • Mivan Technology's features include fast construction speed and reduces the requirement for expert workers for masonry and rendering tasks [28]. • It is easy to adapt and highly cost-effective because it may be used repetitively up to 200 times overall under different circumstances [28].

Construction based on lean techniques has already been undertaken in the Bangladeshi construction industry, but no further progress has been made on the implementation process. Few major and complicated construction projects (financed by the World Bank, ADB, and JICA) use the widely acclaimed lean principle, however, there is no actual study of lean construction adoption (recognition, advantages, and difficulties) [29].

Phenomenon of Construction Industry in Bangladesh

From the last three decades, Bangladesh has seen a great improvement and pioneering development in the construction business. The Padma Bridge, Ruppur Nuclear Power Plant, Rampal Coal-based Power Plant, Metro-Rail, Payra Deep Sea Port, and other contemporary construction projects are some of the megaprojects in global construction with historical amounts of investment [7].

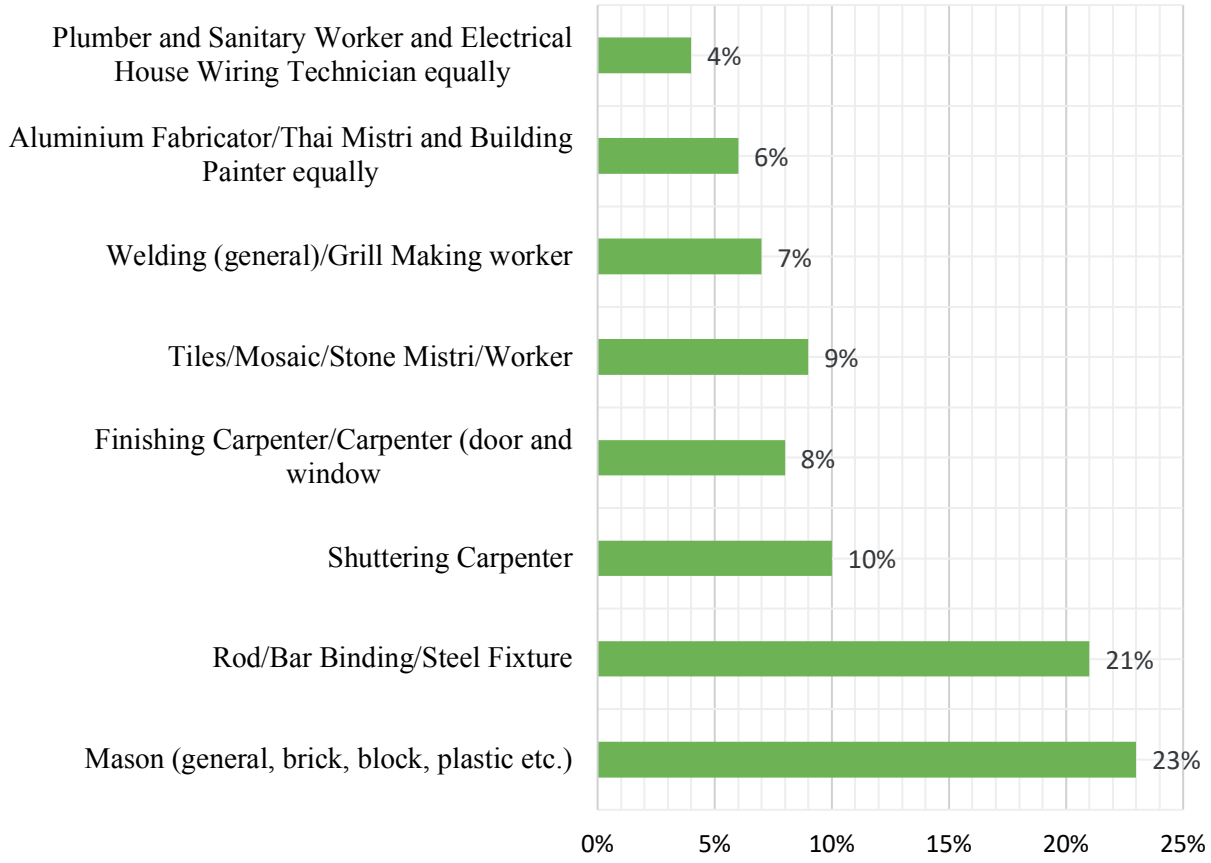
The construction industry employs approximately 3.33 million people, or about 5.6 percent of Bangladesh's overall employment [30], [31]. Bangladesh is presently the world's 27th most attractive investment country, according to a World Bank assessment from 2013 [32]. Several countries have invested billions of dollars in Bangladesh's infrastructure development. Only China has invested more than 3.8 billion dollars in Bangladesh in recent years, and Bangladesh and China have a loan deal for another 2 billion dollars [33]. In recent years, Japan, India, Europe, and the United States have all invested significantly more in Bangladesh than ever before [34].

Bangladesh's strong brand is mostly available at affordable labor costs of low paid employees. There are several semi-skilled and untrained workers available who are prepared to work for a low salary [32]. According to the Bangladesh Association of Construction Industry (BACI), Bangladesh has 4000 construction firms, with 100 of those qualified to resolve issues even in other nations [32]. When significant infrastructure projects like massive bridges were built in the past, equipment from outside the country was employed, but currently the majority of the equipment used in the projects is implemented by foreign corporations but provided by local firms [32]. The construction sector is expected to be extremely active over the next five years as a result of the strategy for mega projects and massive infrastructure.

Current Construction Employment Scenario in Bangladesh

Manual laborers do most of conventional construction work. According to [35], approximately seventy-one percent of the workforce of the surveyed firms were at the workers level. It has also been found that the majority of current vacancies are for semi-skilled and skilled individuals. Figure 1 shows the ten major activities in particular building construction sectors. It represents the percentage of major occupations in the building construction subsector.

Figure 1: Employment in Construction by Occupations in Bangladesh



The ascertain value of the growth rate might be due to the labor-intensive character of the investigated sectors.

Recent Mega Projects in Bangladesh

Construction megaprojects are key attributes of economic growth in a country like Bangladesh. The country's Gross Domestic Product (GDP) growth rate is higher than that of neighboring nations like India, Sri Lanka, Pakistan, and Bhutan [19]. It is to be noted that the majority of the modern megaprojects are being built by foreign businesses and using their expertise. Although the provisions, successful training of our own workers has been impossible owing to a lack of academic competency and expertise with advanced technologies [19]. The following table (Table 4) shows recently initiated mega projects taken over by the government of Bangladesh.

Table 4: Recent Mega Projects in Bangladesh

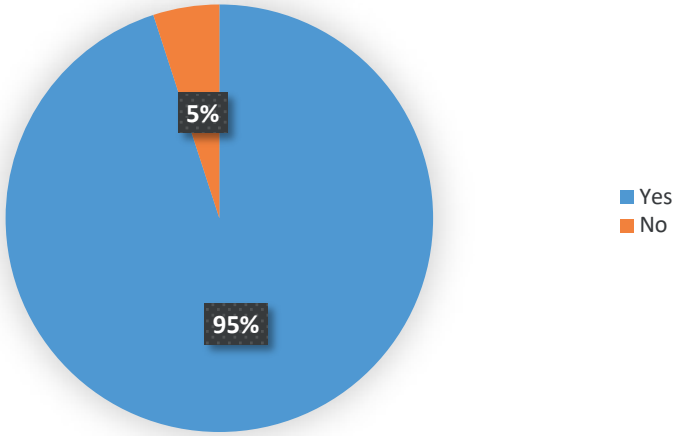
Type	Project Name	Timeline	Estimated Cost	Funding
Power Project	Rup-pur Nuclear Power Plant	Began in November 2017 and is scheduled to be finished by 2025.	USD 12.65 billion	USD 11.38 billion taken as loan from the Russian Government
	Rampal Coal Power Project	Began in April, 2017 and is scheduled to be finished by 2021	USD 5 billion	Financing of Main Plant by EPC (Turnkey) and package by Indian EXIM Bank
	Matarbari Power Plant	Began in July, 2014 and is scheduled to be finished by June, 2024	USD 4.4 billion	Majority of funds provided by Japan International Finance Agency (JICA)
	Moheshkhali LNG Terminal	Began in 2017 and is scheduled to be finished by April 29, 2019	USD 179.5 million	International Finance Corporation (IFC), CDC Group, Development Bank of Germany, JICA and Dutch-led Entrepreneurial Development Bank
Communication Infrastructure	Padma Rail Link	Began on January 1, 2016 and is scheduled to be finished by June 30, 2024.	USD 4.63 billion	The Ministry of railways
	Padma Multipurpose Bridge	Began in January, 2009 and has already finished in 23 June 2022.	USD 3.65 billion	Self-funded by the Bangladesh government
	Dhaka Metro Rail Dhaka	Began in July, 2012 and is scheduled to be finished by December, 2021.	USD 2.82 billion	Japan International Cooperation Agency (JICA)
	Karnaphuli Underwater Tunnel	Began in December, 2017 and is scheduled to be finished by 2022.	USD 2.49 billion	Bangladesh Bridge Authority
	Chattogram-Cox's Bazar Railway Link	Scheduled to be finished by June, 2022	USD 2.13 billion	Asian Development Bank, The Government of Bangladesh
	Dhaka Elevated Expressway	Began in 2011 and is scheduled to be finished by March, 2022	USD 1.63 billion	Italian-Thai Development Public Company, China Shandong International Economic and Technical Corporation Group
	Dhaka-Chattogram Express Railway	Began in October 1, 2018 and is scheduled to be finished by March, 2022	USD 1.4 billion	The Government of Bangladesh

	Payra Deep Sea Port	Implementation of the revised project started in January, 2019. Will be completed by December, 2021.	USD 98.5 million	Foreign Direct Investments (FDI) and government-to-government (G2G) deals
	Hazrat Shahjalal International Airport Expansion	Began in December, 2019 and is scheduled to be finished by 2022.	USD 42.1 million	Civil Aviation Authority, Bangladesh (CAAB)

Questionnaire Survey in Bangladesh's Construction Industry

This research is relied on the quantitative survey on Adaptation of Modern Construction using Advanced Technology: the Perspective to Bangladesh. Civil engineers, construction workers, research assistants and all that took part in this questionnaire survey believe that employing advanced technology in the construction sector may save a significant amount of time and modern construction is earnestly needed for better economic prosperity of a country. The pie chart (Figure 2) below depicts the percentage about going with modern technology or not –

Figure 2: The Percentage about Adopting Modern Advanced Technology or not



Ninety five percent of the surveyed believes that if Bangladesh adapts modern advanced technology, it will be a significant benefit. According to a questionnaire, individuals assume that advanced technology is usually beneficial to social life by employing this modern technology. Bangladesh can be a role model for underdeveloped countries, and they can save money on development by not hiring overseas consultants and increase per capita income. According to the report of the questionnaire, the construction business in Bangladesh is dominated by labor-intensive technology, lower-quality materials, and inappropriate building

methods. As an outcome, Bangladesh's building industry has become ineffective. According to the field research findings, Modern construction is vital for better and more cost-effective building. During an interview, construction workers mentioned concerns that mechanization might lead them to lose their jobs. However, this is not the case in practice. According to the author's findings of advanced nations engaged in totally automated building mechanization, there was no rise in unemployment [18].

SWOT Analysis of Adaptation of Modern Technology in Construction Industry in Bangladesh

For understanding a better scenario on the path of implementing advanced modern technology in the construction sector of Bangladesh, a SWOT analysis (Table 5) has been done on the basis of different literatures review [32] , [36].

Table 5: SWOT Analysis of Advanced technology on Construction Sector in Bangladesh

SWOT Analysis of Adaptation of Modern Technology in Construction Industry in Bangladesh	**Positive**	**Negative**
	Strength	**Weakness**

Internal Influence	• Electronic procurement system has been fully implemented [31]. • Many construction firms employ workers, architects, and engineers with international and local experience. • By employing both foreign and local skills, minimize the additional expenditures connected with offshore design and engineering experts. • Bangladesh Association of Construction Industry (BACI) claims that Bangladesh has 4000 construction enterprises, with 100 of them are efficient of completing projects [32]. • Another asset of the building sector is the availability of low-cost skilled and unskilled labor. • Bangladesh has one of the most sound and liberal FDI (Foreign Direct Investment) packages in South Asia, allowing 100 percent foreign equity. Also Bangladesh provides a wide range of tax incentives to FDI investors [1].	• Lack of advanced construction technology. • The construction and architectural companies in Bangladesh are less interested to do overseas projects. • Unskilled labor forces who are not prepared for the adaptation of advanced construction technology. • Lack of trainings for adapting the modern construction technology. • Improper procurement route for both big and small projects. • Proper linkage is not maintained between the construction companies and research institutions. • Inadequate coordination among the several ministries involved in building, design, and urban planning. • Political unrest and natural calamities.
	Opportunities	**Threats**
External Influence	• The contribution of the construction industry in GDP (Gross Domestic Product) is 10-15% which can be increased into a higher percentage with the help of advanced technology and skilled labor. • The cheap labor force can be utilized in this sectors with proper trainings. • Only a few reputable and large construction companies are typically observed working on projects in the Middle East or Africa. Some small businesses have promises as well, but they are unable to pursue overseas initiatives due to a lack of motivation and confidence. Joint ventures may	• Price hike of construction materials. • The Public Procurement Regulations 2003 doesn't include price adjustment, 'mobilization fund' and 'escalation clause'. • There has been no major FDI (Foreign Direct Investment) in the construction sector in particular. • For many years, Bangladesh has struggled to measure and improve its performance in the construction industry due

	allow them to expand into international projects.	to a number of fundamental challenges. Poor safety, schedule delays, inexperienced labor, quality difficulties and cost overrun are the most commonly encountered challenges [30], [33], [37], [38], [39], [40].

Analysis Over The Purpose Of Using Advanced Construction Technology İn Bangladesh

Technological Usage Analysis

It has been defined that Mivan Technology is suited for mass structure building in India, where great levels of quality and speed may be attained at a reasonable price [28]. This specific technique is being used to create a number of structures in Mumbai, and it has been deemed very cost-effective. To execute the most difficult government program, Housing for all, by 2022, Mivan Technology is embraced in India [41].

Table 6: Different source data collection including cost estimation

Reference Source	**[28]**		**[42]**	
Type	**Conventional Technology (P+7 storied building)**	**Mivan Technology (P+7 storied building)**	**Conventional Technology (50 Repetitions/70 sq. m/staircase)**	**Mivan Technology (50 Repetitions/70 sq. m/staircase)**
Total Cost	USD 611957.75 (57625853 BDT)	USD 536639.87 (50533440 BDT)	USD 13000.92 (1224250 BDT)	USD 12029.77 (1132800 BDT)
Duration (days)	167	98	10-15	4-5
Labor Cost	Not included	Not included	USD 4229.22	USD 2819.48
% of savings compared to Conventional Technology	12.5		13.5	

The above table (Table 6) illustrates that when one compares Mivan technology to traditional technology, the overall cost including the labor cost is substantially lower, but when one looks objectively at material costs, it is marginally greater. Furthermore, Mivan technology outperforms conventional formwork in terms of building cycle, labor cost, resilience, and

efficiency. It reduces the demand for trained labor necessary for tasks like masonry and rendering thus reducing the labor cost.

Labor Market Analysis

According to the field research findings, the history of the link between technical development and the future of labor is complicated [43]. Interactions between employees and technologies highlight the link between technology, skills, and tasks [44]. Such undertaking models distinguish between a worker's competencies and the activities they do on the job [45], [46], [47].

In Bangladesh, The average wage for skilled construction workers was 499.0 BDT (USD 5.31) in June 2015, with a low of 109.150 BDT (USD 1.16) in November 2006 [48]. Unskilled employees' wages were 401.0 BDT (USD 4.27) in June 2015, peaked at 417.0 BDT (USD 4.44) in September 2012, and declined to a record low of 78.750 BDT (USD 0.84) in January 1999 [49]. Data collected from four locations (Dhaka, Chittagong, Rajshahi, and Khulna) demonstrate that construction workers' wages have been growing over the previous 10 years, with the Bangladesh Building Construction Cost Index standing at 744.090 in February 2022 [50].

The information also reveals that there is a strong correlation between worker pay and construction skills. Skilled workers are paid at a higher rate than the unskilled workers. While adapting modern construction technologies, there will be a greater need for skilled workers. Mechanization unquestionably creates some unemployment issues in the construction industry at first, but it will generate more opportunities for skilled workers in the long term. The more skilled the workers will be, the higher they will be paid. We can simply standardize modern construction technologies with the aid of trained people. Therefore, ultimately the employees will be benefitted. With their expertise, they will be even able to work abroad and contribute to remittances. Additionally, the use of new technologies in construction speeds up the process and ensures safety at work. In Bangladesh, laborers always work in a hostile environment. Therefore, the workers' safety is a major concern. Because modern technologies employ strong standards of safety, injuries will be kept to a minimum in the construction zone and lives will be saved.

Construction Market Analysis

People believe that laborers may have lost their employment with the use of modern advanced technologies. On the plus side, industries may employ construction technology equipment to speed up the construction process. In Bangladesh, some of the factors that cause significant delays in any construction projects are lack of experienced construction managers, unauthorized project scheduling by contractors, misleading project budget, inexperienced contractors, outdated development techniques and methodologies, a shortage of skilled workers, unapproved assessment processes, and improper cost control [51]. This issue can be resolved by incorporating modern technologies. Modern technology is utilized with proper planning and scheduling. With the assistance of advanced technologies, skilled workers and experienced engineers can alleviate schedule delays and even accelerate the speed of construction. The employment of current technology will undoubtedly save time because technology is faster than manual labor in terms of quality, and the overall quality of the final product will be higher when compared to labor. People believe that utilizing modern technologies would improve the construction industry. As a consequence, it is better and more effective, increasing the productivity and efficiency of the construction phases. According to reference [52], a construction company should invest in modern advanced construction technology to improve the efficiency and quality.

Discussion and Findings

The essential part of the study is the literature review and the surveyed data. The study's primary objective was entirely dependent on the integrity of the data, analysis, and explanation. Graphical representation, the percentage approach, different markets study and SWOT analysis were used to analyze the intention of adapting advanced modern technologies in Bangladesh. Improved and more positive development needs the assistance of technologically linked services and equipment. The majority of current megaprojects were developed by foreign firms using their knowledge rather than employing local workers as well as using advanced technologies. To enhance project-site performance as well as limiting the tendency to hire foreign firms, it is crucial to implement modern advanced technology and instruct and familiarize our work force with it. The ongoing mega-projects, available high-rise constructions, and contribution of the construction industry to Bangladesh's GDP (Gross Domestic Product) demonstrate the sector's enormous prosperity and ongoing demand. If

Bangladesh wants to keep pace with the modern world and make significant progress in this field, adaptation of modern technology is a need of time.

The study of mega projects in Bangladesh provides us the statistics about the cost and time needed for the completion of it. From the analysis of advanced technologies, it is clearly found that time and cost will be reduced with the implementation of them. The questionnaire survey of this study has found that ninety five percent thought modern technology would be adapted for the benefits of the construction sector. The SWOT analysis has found that poor safety, unskilled labor force, lack of proper training and co-ordinations are the main challenges in the sector of construction, whereas cheap labor force, foreign and local experiences, attractive Foreign Direct Investment (FDI) packages could act as an asset for this sector. The link between technology, skills, and jobs would be clearer, if the interaction between employees and technologies was typically adopted. According to the assessments of technological, construction, and labor market analysis, Bangladesh should embrace advanced modern technology.

Recommendations

Some strategies are recommended for utilizing the strengths of our construction sector as well as dealing with the challenges of it in embracing the advanced technology.

- By effectively utilizing the foreign and local experiences, it is possible to minimize the additional expenditures associated with overseas design and engineering experts.
- Proper training and knowledge of modern construction technologies can help to build a clear understanding among individuals in the construction industry and prepare a skilled workforce for use.
- A favorable environment for adapting modern construction technology can be created by proper linkage between construction enterprises and research institutions, as well as coordination between the several ministries involved in construction, design, and urban planning.
- Joint ventures between renowned and major construction corporations and some small enterprises may allow them to develop their operations into worldwide projects.
- A significant Foreign Direct Investments (FDI) in the construction sector can help as

well.

- Further research is encouraged to promote the adaptation of new technologies.

Conclusion

In conclusion, the study attempts to provide an insight and overview of using the new advanced technology and its adaptation from the viewpoint of Bangladesh in the construction sector. From analysis through literature and survey and taking a long term view of Bangladesh, it is found that there are promising opportunities to be made. The construction industry's contribution to GDP (Gross Domestic Product) may be expanded to a larger proportion with the support of sophisticated technology and trained personnel, which has the power to transform Bangladesh to a developed country. Bangladesh has undertaken numerous initiatives to achieve the 'Vision 2021,' it is now imperative that the construction sector addresses the constraints impeding its ability to contribute to the GDP (Gross Domestic Product) and attract infrastructure trade. The adaptation of modern technology can improve this construction industry in such a way that it becomes the most significant and prominent in the contribution scale, therefore transitioning Bangladesh from a Least Developed Country to a Developed Country.

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Life Cycle Cost Analysis of Pavement Improved Using Bio-Char and Geo-Char

Saadoon Obaid Eyada[1]

Yavuz Yenginar[2]

Silda Doori[3]

Abstract

Biochar (BCh) is one of the products of Pyrolyzation of Biomass. It is used as fertilizer for soil and planting. The application of this material in the field of soil stabilization has not been used yet. In this work, Mushroom Spent Compost (MSC) is converted into BCh using pyrolysis technique. The BCh is mixed with Low Plasticity Clay soil using different types and percentages of alkaline activator to produce newly known Geo-Char (GCh). The aim was to find a new method for soil stabilization using waste material. The results were assessed using Unconfined Compressive Strength (UCS) test. The results showed that there is a significant increase in soil strength (UCS) by 176% when the soil mixed with 10% BCh. The new produced GCh using sodium hydroxide has increased the UCS by 147%. The results also recommended not to use potassium hydroxide to produce GCh until further studied can be conducted with more deep chemical and mineralogical investigations. The results of Mechanistic Empirical analysis showed significant increase in pavement life due to the use of BCh and GCh. The results of LCCA showed that the use of BCh decreased the pavement cost during its life by 24%, while it was between 21-23% when using GCh.

Keywords: Geopolymer, BioChar, Geo-Char, Soil improvement, Alkaline activator, Mushroom waste, M-E pavement analysis.

Discipline: Science and Engineering

[1] PhD., Civil Engineering Department, Konya Technical University, Konya, Turkey; ORCID: https://orcid.org/0000-0001-9613-4940.
(E.mail: Saadooneyada@gmail.com). (**Corresponding Author**)
[2] Research assistant, Civil Engineering Department, Necmettin Erbekan University, Konya, Turkey; ORCID: https://orcid.org/0000-0002-6916-4068.
[3] Msc. Candidate, Civil Engineering Department, Selcuk University, Selçuklu, Konya, Turkey; ORCID: https://orcid.org/0000-0002-0977-1253.
(E.mail: eng.seldagazi@gmail.com).

Introduction

The improvement of soil strength is a very useful technique for road, airfield and other application in civil engineering. Soil stabilization can be achieved by alteration of one or more of soil properties to create an improved soil structure of enhanced engineering properties. The use of soil stabilization products for the stabilization of fine-grained soils includes the use of Traditional materials i.e. cement, lime, cement kiln dust and coal fly ash, or Non-traditional stabilizers, which can be subdivided into four groups after Scholen (1992) [1, 2]: electrolytes, enzymes, clay fillers, and acrylic polymers.

The disadvantages of using these materials are; High cost (e.g. polymers) and Adverse effect on environment (e.g. cement) [3, 4].

Geopolymer is an inorganic material formed via interaction between alkaline activator and (Aluminia and Silica)-Containing material. Through which the polycondensation process is taking place where the tetrahedral Silica (SiO2) and Alumina (AlO4) are linked together through sharing the oxygen atoms. In general, the chemical structure of geopolymer can be expressed in Eq. 1 [5, 6].

$$M_n[-(SiO_2)_q\text{-}AlO_2\text{-}]_n \qquad (1)$$

where M: alkali cation, n: the degree of polycondensation and q: Si/Al ratio. Researches showed that using wide range of materials such as, furnace slag, fly ash, rice husk ash and metakaolin can produce geopolymers with high compressive strength, less shrinkage susceptibility, acid and good fire resistance properties [7-9].

Geopolymer applications in soil stabilization are limited. The researches in this field can be considered rare. Kim et al. (2011) enhanced the properties of loess paste through Geopolymerization. Alkali solutions is used for this purpose. The results showed the feasibility of using geopolymer in stabilization of loess soil [10].

Kajal (2015), stabilized two difficult soils; expansive and dispersive soils with geopolymer. Sodium based alkaline activator and fly ash were used to produce geopolymer. It was found that 40% of Fly ash and between 10-20 % of pentonite enhanced the Unconfined Compressive Strength UCS and reduced swelling potential of the soil [11].

Rosky and Fumyoshi (2015) studied the effect of geopolymerization of dredged soil using EAF

slag waste from steel manufacturing. The results were investigated in term of UCS. An improved strength was achieved through geopolymerization process. It was found that the strength of mixture is affected by mixing ratio rather than curing time [12].

Sara Rios et al. (2016), investigated the soil stabilization using geopolymer made from fly ash and alkaline solution for the application in unpaved low volume roads. The UCS results of geopolymer soil was improved and the strength was similar to Cement-Stabilized soil used in low volume roads [13].

In a study by Zhang et. al. (2013), a lean clay was stabilized with metakaolin-based geopolymer at different concentrations and the feasibility of geopolymer was investigated. The results showed that UCS, failure strain and elastic modulus of the stabilized soil was increased wile shrinkage strains during curing decreased at certain ratio of geopolymer. It was concluded that metakaolin geopolymer can be used for soil stabilization [4].

One of the major wastes during the cultivation of mushrooms is Mushroom Spent Compost (MSC) as shown in Figure 1. For the cultivation of I kg of mushroom about 5 kg of MSC are disposed as a waste. The amounts of MSC disposed in EU is about 5.6 million Mg per year [14, 15]. The white mushroom (Agaricus bisporus) is grown on a bedding consisting mainly of straw and poultry manure. The production of mushroom takes about 6 to 8 weeks. After this period, the MSC cannot be reused again for the production and there is a need to be treated or disposed [15, 16].

Figure 1. Photograph of MSC.

Many researches concerned about the use of MSC as fertilizer for soil and planting [16]. But

MSC does not always meet criteria for a fertilizer due to the high variability of the compost parameters such as N, P, Ca, Na, Mg, Cr, Cd, biogenic elements, pH, C/N ratio and electrolytic conductivity.

So it is important to find a new solutions to reuse MSC in term of cost effectiveness and protection of environment which is one of the goals of this work.

Objectives

1. Improving the properties of soil using Bio-Char (BCh) which can be an economical solution for millions of tons of MSC waste.
2. The use of BCh for soil improvement can decrease the adverse effect of MSC wastes on the environment.
3. Using of BCh can be an economical solution for soil improvement.
4. Success in this field, can open the gate for further researches in this virgin area of civil engineering.

Therefore, according to the goals of this work, this paper describes the potential of utilization of BCh produces from MCS as an active material for the production of Geo-Char (GCh) by mixing with Low Plasticity Clay CL soil using alkali activator as a new method for soil stabilization. Ten percentage of BCh were mixed with soil and Alkaline Activator AA using different types of hydroxides (NaOH and KOH). AA was prepared by mixing one portion of Sodium Silicate SS with two portions of each type of Hydroxide H. The Optimum Moisture Content OMC of each mix was determined using new approach by using UCS test method. Samples were cured in moisture condition for 14 and 28 days. UCS test was conducted to characterize the mechanical properties of G-Ch.

Mechanistic-Empirical (M-E) Analysis

The results of UCS were used in Mechanistic-Empirical (M-E) analysis. Since the M-E processes cannot be made by hand, the Minnesota M-E design software MnPave ver. 6.3 was used (with permission) for the analysis and assessment of the effect of BCh on Fatigue Life FL and Rutting Life RL of selected section.

Antalya city in Turkey was selected to represent the hot climate condition. The properties of

each layer of the selected pavement structure are shown in Table 1. The traffic loading 20 million ESAL was selected. Asphalt type B50-70 was used for the asphaltic layers.

Table 1. The implementation program used in the M-E analysis process using MnPave.

	Pavement structure				
Layer type	**Asphaltic Surface**	**Asphaltic Binder**	**Asphaltic Base**	**Unbound Base**	**Sub base**
Thickness, cm	5	8	10	20	35
Strength, Mpa	-	-	-	221	125

It is required for the M-E analysis to use Resilient Modulus MR of subgrade layer. For this reason, the results of UCS of subgrade layer with and without BCh after 28 days of curing were converted to MR using equation 2 [17, 18] .

$$M_R(\text{Mpa}) = 0.124\ \text{UCS(kPa)} + 68.8 \qquad (2)$$

Life Cycle Cost Analysis LCCA

Today, pavement construction and rehabilitation costs are rising dramatically. It is essential to use tools and approaches that facilitate proper decision-making by applying economics approaches such as Life-Cycle Cost Analysis (LCCA) to achieve long-term investments.

The FHWA report FHWA-SA-98-079, Life-Cycle Cost Analysis in Pavement Design defines life-cycle cost analysis (LCCA) as [19]:

"…an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It does not address equity issues. It incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures.". So it is an economic based method. It provides the ability of estimation of the total long-term economic viability of different options. This method play a significant role in pavement design and LCCA should be used as a decision support tool when selecting pavement type, determining structure and mix type (for flexible pavements),

construction methods, as well as maintenance and rehabilitation strategy.

Typically, LCCA involves the following basic steps:

1. Make initial strategy and analysis decisions: Specific initial decisions, calculations and assumptions are needed to determine the factors under which LCCA can be implemented.
2. Estimate costs: Costs associated with transportation agency and users are calculated for each choice.
3. Compare choices: Comparison can be made according to specific metrics such as Net Present Value (NPV) or Benefit/Cost ratio (B/C).
4. Analyzing of results and Re-evaluate choices: Results should be checked for the most effective costs, factors and assumptions. Sensitivity Analysis is often used to do this and to Re-evaluate different design strategy alternatives to improve the cost-effectiveness of each alternative.

The successful LCCA is the selection of the most cost-effective design strategy for a given situation. It is recommended that factors influence cost effectiveness of alternatives should be understood [20, 21].

In order to facilitate LCCA, several software are made. LCCAExpress software is one of the publication of Asphalt Pavement Alliance APA and can be considered as one of the commonly used software for LCCA. LCCAExpress software, version 2.0, developed by Timm (2011), was used for conducting the life-cycle cost analysis in this study. The accuracy of LCCA results depends on the accuracy of each of the inputs. The software inputs include unit prices of the materials in the pavement structure, construction and rehabilitation activities/costs during its service life and recurring maintenance activities/costs in order to compute the Net Present Value (NPV). The screenshot of the software is shown in Figure 2.

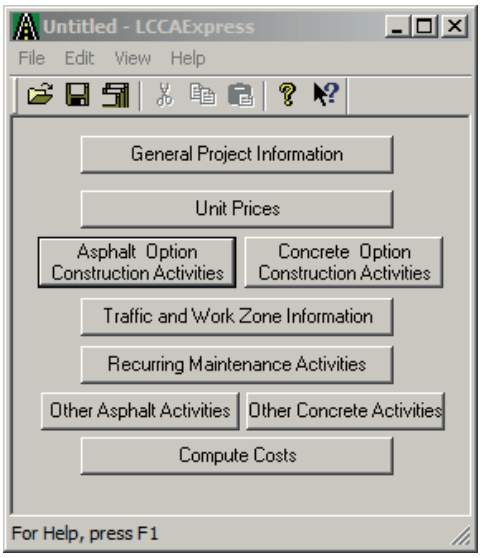

Figure 2. Main menu screenshot of LCCAExpress software.

LCCAExpress software is used to conduct LCCA for each section for a period of 35 years. Approximate unit prices for construction, milling and overlay operations that were used in the LCCA analysis are given in Table 2. The prices were supplied per square metre for all layer thicknesses of all cases. The rehabilitation cost included both milling of existing layers and overlaying of new layers. In addition, the overlaying cost for unbound layers should be ignored in this analysis because they will not be removed or milled. The overlay cost is assumed to be the same as construction cost. The work-zone user costs is not included in LCCA.

Table 2. Average unit prices for construction and rehabilitation processes.

Description	**Construction, $/ton**	**Milling, $/sy**	**Overlay, $/ton**
Asphaltic Surface	110	5.8	110
Asphaltic Binder	106	-	106
Asphaltic Base	102	-	102
Unbound Base	34	-	-
Sub base	21	-	-

Other data required by the software are as follows:

- Road length is one mile (1609 m) long and 24 ft. (7.32 m) wide.
- Road has two lanes in each direction.
- Lane width is 12 ft (3.66 m).
- Speed limit is 60 mph (96.56 km/h).
- Overlay and milling thickness s are the same.
- Discount rate is 4%.
- Design life 35 years.

The Unbound Base and Sub base layers were combined due to limitation of number of layers in the software and the unit price is averaged. The rehabilitation strategy is Milling and Overlaying of Surface layer.

Experimental Work

Materials and Methods

The MSC is obtained from local company in Turkey. The white mushroom (Agaricus bisporus) waste is used for the production of BCh using pyrolysis process. It is dried in the oven for 48 hours under 60 $_{o}$C temperature.

Bio-Char

Two litters of dried MSC is added to the reactor of pyrolysis instrument. The pyrolysis temperature was increased at a rate of 5 oC/min for about 2 hours. The maximum temperature was 484 oC. The BCh was extracted from the reactor and milled using roller mill for about 3 hours. The BCh powder used in testing program was sieved using sieve No. 200 (less than 75 micron). The yields of BCh was 58% of the MSC. Figure 3 shows an image of Scanning Electronic Microscopy SEM of BCh in the range of 2 microns. The results of SEM of BCh are shown in Table 3.

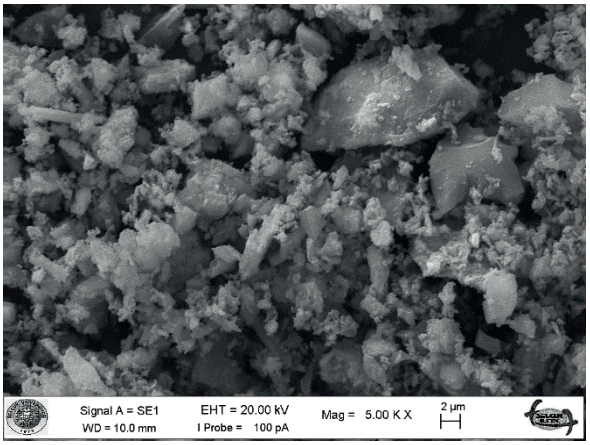

Figure 3. SEM image of BCh in the range of 2 microns.

Table 3. The results of SEM test of BCh.

Element	**Weight, %**	**Atom, %**
Oxygen	43.78	68.39
Silicon	17.11	15.23
Calcium	2.58	1.61
Potassium	1.16	0.74
Aluminium	2.13	1.97
Carbon	4.24	8.83
Magnesium	1.67	1.72
Iron	0.94	0.42
Sodium	0.67	0.72

The results of X-Ray Diffraction XRD test are shown in Figure 4 while the percentages of chemical composition are tabulated in Table 4.

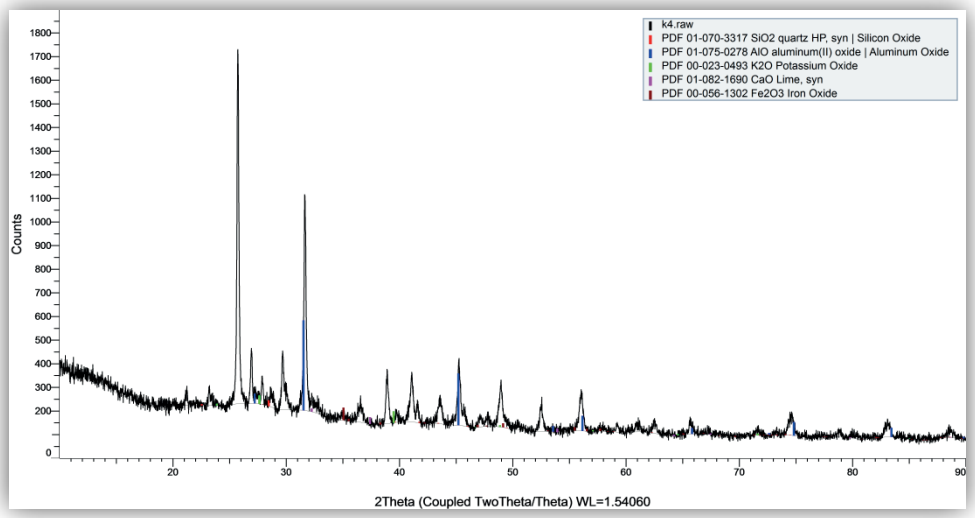

Figure 4. XRD scheme of BCh.

Table 4. The results of XRD test of BCh.

Compound Formula	%
SiO_2	4.1
AlO	49.3
K_2O	20.8
CaO	2.8
Fe_2O_3	23

The results of SEM show that there is a large amount of Oxygen. These amounts are consumed in the interactions with Al, Si and Ca for the formation of AlO, CaO and SiO2. This agreed with the results of XRD which showed that there is a high percentage of AlO (Aluminate) which is the main compound in the manufacturing of geopolymer. Aluminate condensation reactions involving aluminate species appear to occur much more readily than silicate due to positive partial charge of the Al atom [22].

CL soil

This type of soil is distributed over a large area in Konya city in Turkey. The properties of this soil is tabulated in Table 5. Sieve analysis of the soil is illustrated in Figure 5. This type of soil consists mainly of clay and sand. It is known that this type of soil has a high collapsibility [23].

Table 5. The basic properties of CL soil.

Property	**Value**	**Standard**
Liquid limit, wL	35.2 %	ASTM D4318 (ASTM 2010)
Plastic limit, wP	20.4 %	
Plasticity index,	14.8 %	
Clay+Silt fraction	65.3 %	ASTM D2217 (ASTM 1998),
Sand fraction	25.15 %	
Soil classification	CL	ASTM D2487 (ASTM 2011)

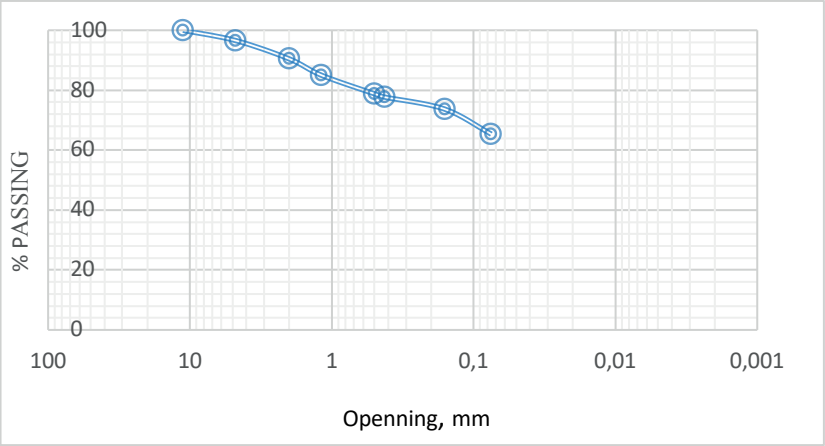

Figure 5. Gradation of CL soil.

Blends and Tests

The experimental plan consists of trial blends by mixing soil, BCh and AA. Table 5 illustrates the blend used in testing program.

OMC of blends

The OMC of the blends was determined following the procedure conducted by B. Sharma et al. [21]. Table 6 tabulates the OMC values of each blend.

Table 6. Blends properties and OMC of each blend.

Blend type	BCh %	Hydroxide type	AA=SS/H	OMC	Dry density at OMC
SB0	0	-	0	19	1.71
SB10	10	-	0	22.5	1.61
SB10S	10	NaOH	0.5	27.5	1.51
SB10K	10	KOH	0.5	27.5	1.51

Figure 6, shows the Moisture-Density relationship of each blend. The curve of SB10K is emerged with the curve of SB10S.

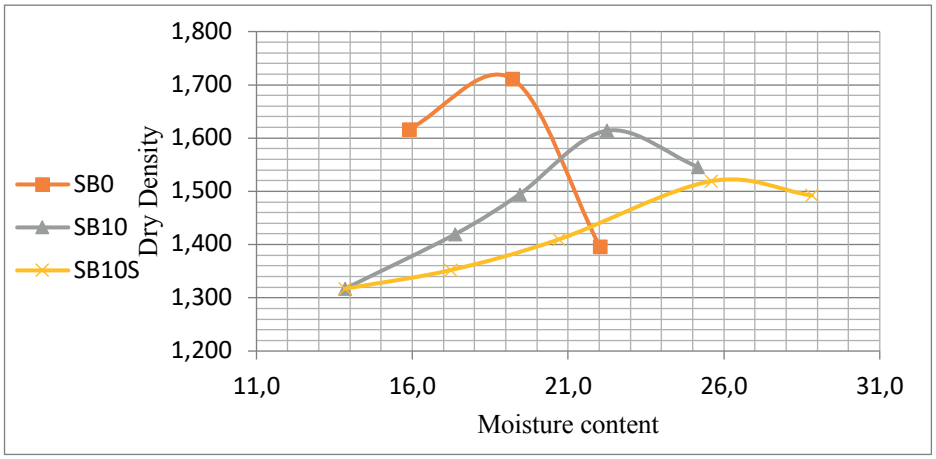

Figure 6. Moisture Content-Density relationship of blends.

Geo-Char

For the preparation of AA, 8 M of potassium hydroxide KH or sodium hydroxide NH is prepared. AA is produced by mixing one fraction of sodium silicate SS with two fractions of potassium hydroxide KH or sodium hydroxide NH. The mix is left overnight at room temperature. In the next day, a dry blend of 10% BCh and 90% soil is mixed and the specified amount of AA and water is added to the dry blend and mixed for 5 minutes. 300gm of the blend is poured into a cylindrical mold of 47 mm diameter and 90 mm height and compacted according to ASTM D1632 [24]. The sample is left in the mold for 24 hours in a moist condition. After 24 hours, the sample is extracted from the mold and kept in moist condition (sealed bag) to be tested for UCS after 7 and 14 days.

Unconfined Compressive Strength UCS Test

Before testing, the mass and dimensions of the samples are recorded. The sample is placed centrally on the lower platen of the compression testing machine. The force is applied with a controlled strain rate of approximately 1 mm/minute. The force is recorded during the test until the failure of the sample. The tests is conducted according to ASTM D1633 [24].

Results and Discussion

Results of UCS

Figure 7 shows the results of UCS after 14 days of curing, while Figure 8 displays the results of UCS after 28 days of curing.

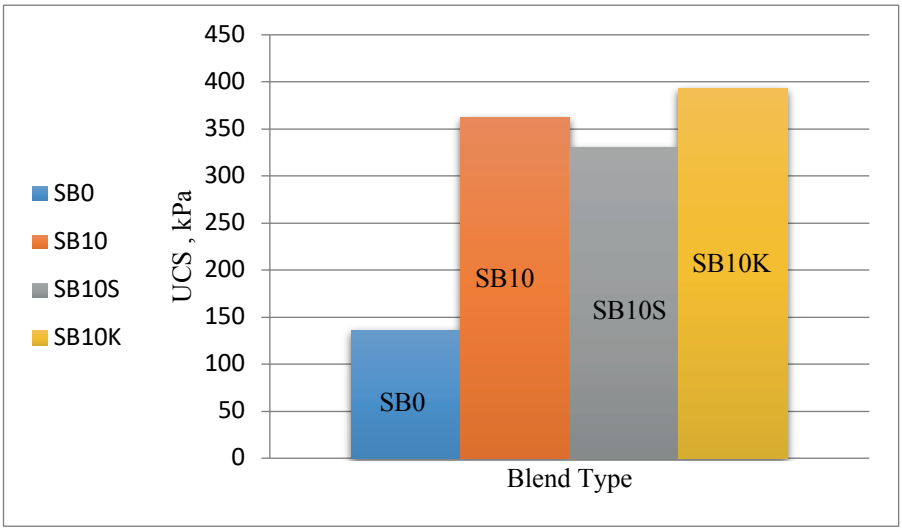

Figure 7. The results of UCS after 14 days of curing for different blends

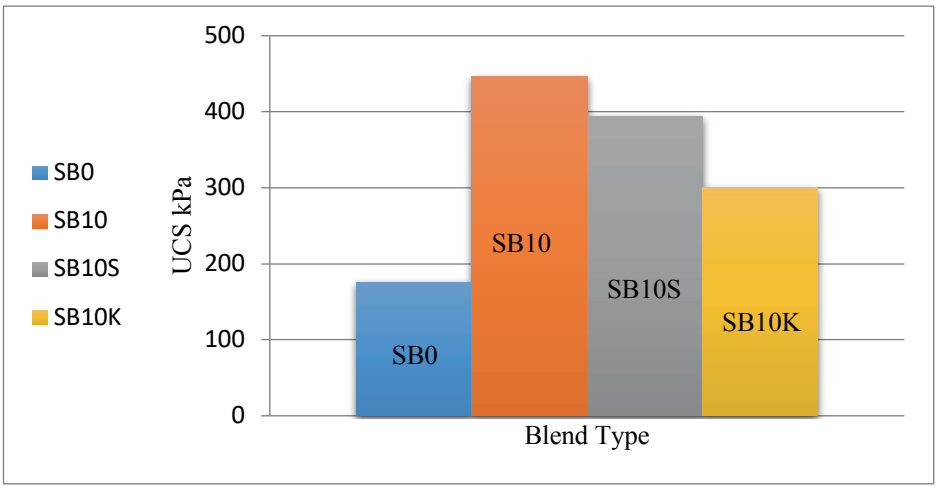

Figure 8. The results of UCS after 28 days of curing for different blends

It is easy to see the effect of produced GCh on the results of UCS. The enhancement is also achieved when using BCh only as shown in the result of the blend SB10. At early stage (14 days), the results revealed that UCS of SB10, SB10S and SB10K are close to each other. This can be attributed to reaction time needed for KH and SH to gain strength by geopolymerization. Nevertheless, SB10K has an advantage over other types of blends. The percentages of enhancement achieved when using BCh to produce GCh for soil improvement can be shown in Table 7.

Table 7. The enhancement achieved using BCh to produce GCh after 14 days

Blend type	UCS, kPa	% Enhancement
SB0	136	0
SB10	362	166
SB10S	330	143
SB10K	393	189

It can be noticed that mixing 10% of BCh with AA using KH doubled the result of UCS compared to soil only. On the other hand, mixing 10% of BCh with soil only increased UCS by 166% compared to 143% achieved when mixing 10% of BCh with AA made using SH.

After 28 days of curing, there were some changes on the results of UCS. Strength gain continued with SB10 and SB10S blends while blend SB10K started to loss the strength as shown in Figure 9. However, in most cases there was a significant increase in UCS results when using BCh and GCh compared to soil only (SB0) as shown in Table 8. It is easy to see that NH provides better enhancement than KH. It is believed that the ion size difference is the main factor that play an important role in the geopolymerization where sodium cations have better zeolitization capabilities because they are smaller than potassium cations [25, 26].

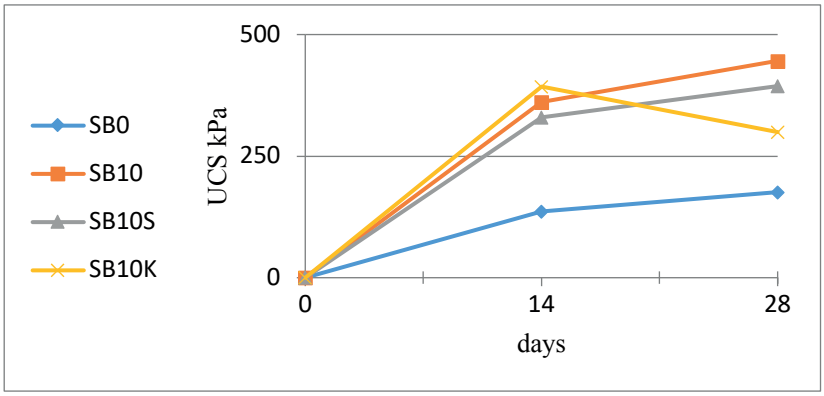

Figure 9. The effect of curing period on the results of UCS.

Table 8. The enhancement achieved using BCh to produce GCh after 28 days

Blend type	UCS, kPa	% enhancement
SB0	176	0
SB10	446	176
SB10S	394	147
SB10K	300	93

The results of XRD show that BCh is Aluminate-Rich. When it comes into contact with the alkaline solution, it dissolves into several species, primarily alumina monomers. These monomers interact to form dimers, which in turn react with each other to form trimers, tetramers and so on. When the solution reaches saturation, an aluminosilicate gel, N-A-S-H gel, precipitates. This gel is initially Al-rich (called Gel 1, a metastable intermediate reaction product) which is responsible for geopolymerization [25].

Results of M-E Analysis

The results of M-E analysis are shown in Figures 10 and 11.

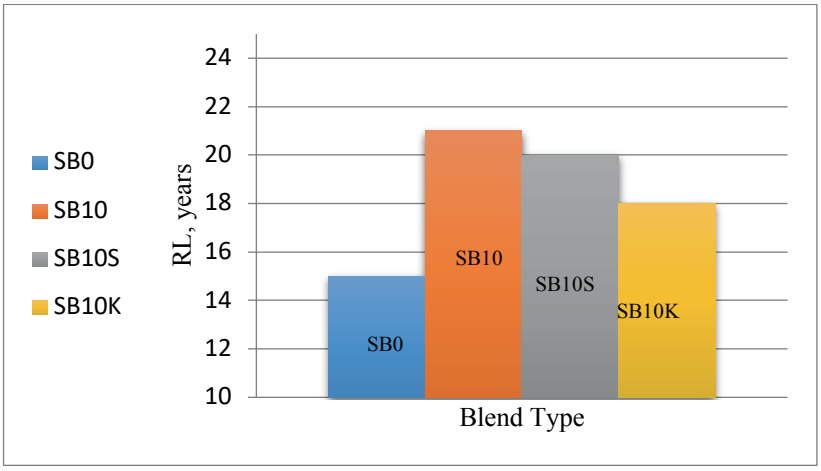

Figure 10. The effect of BCh and GCh on the results of RL

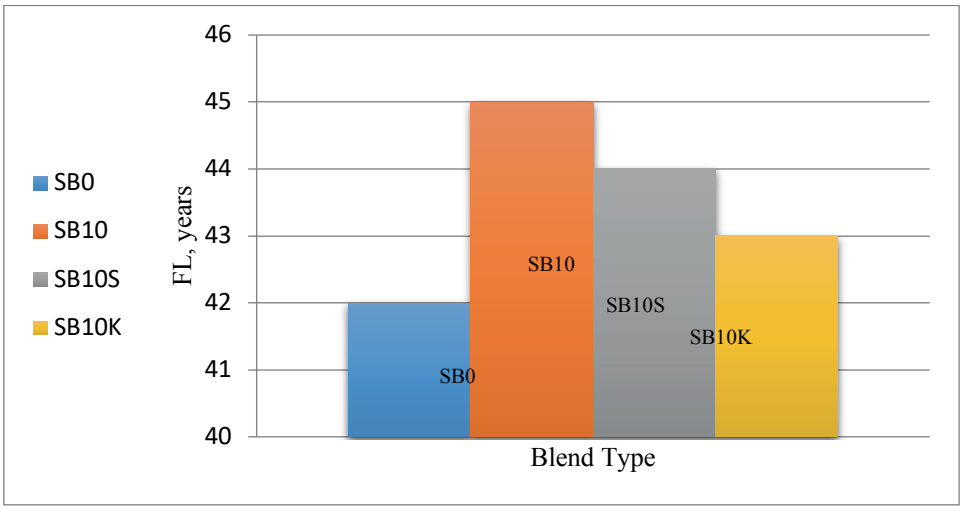

Figure 11. The effect of BCh and GCh on the results of FL.

The results of M-E analysis revealed that subgrade soil treated with BCh (SB10) enhanced the RL and FL of pavement structure significantly compared to untreated subgrade soil. The results of GCh (SB10S and SB10K) also show the positive effect of Geopolymerization on the FL and RL of pavement structure using different types of Alkali activator.

Results of LCCA

LCCA was conducted according to RL. The results of LCCA are shown in Figure 12.

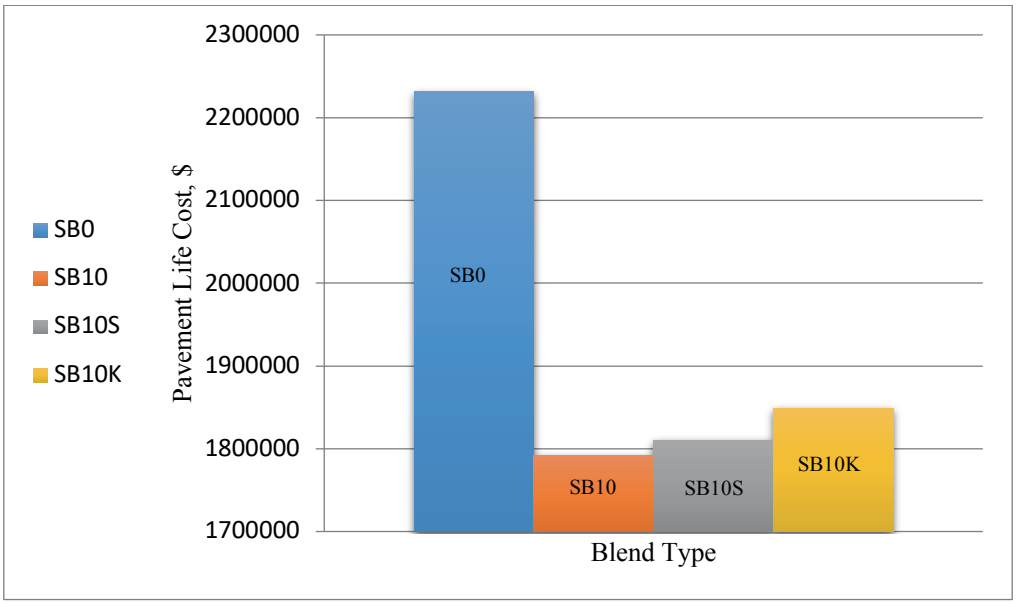

Figure 12. The results LCCA of pavement with and without BCh.

It can be noted that using BCh to stabilize the subgrade of pavement structure reduced the total cost of pavement during its life by 24%. While it was 23% and 21% when using GCh activated with sodium hydroxide and potassium hydroxide respectively. This indicates the previously mentioned results that using of BCh produced from mushroom waste to improve soil strength of pavement can be an economic and environmental solution.

Conclusions

This paper presents an experimental study of using BCh and GCh produced from mushroom waste for the stabilization of collapsible CL soil. Two alkaline activators were used for the production of GCh, NH and KH. The Unconfined Compressive Strength UCS test was used for the assessment of the results. The M-E analysis was used to study the effect of the results on pavement life, while LCCA was used to study the economic benefits of the results. It can be concluded that:

1. There was a significant increase in soil strength (UCS) by 176% when the soil mixed with 10% BCh.
2. The utilization of BCh for the production of GCh using NH increased the strength of soil (UCS) by 147%.
3. Using KH to synthesize GCh increased the soil strength (UCS) at 14 days by 189%. After the day 14, this percentage started to decrease and reached 93% at 28 day. It is not recommended to use KH to produce GCh until further studied can be conducted with deep chemical and mineralogical investigations.
4. The M-E pavement analysis show the significant of using BCh and GCh to enhance the FL and RL of pavement structure. The increase in FL and RL can decrease the cost of periodic rehabilitation of pavement.
5. LCCA shows that the use of BCh to enhance subgrade can decrease the pavement cost during its life by 24% while it was between 21-23% when using GCh.
6. The results show the Cost-Effectiveness of using BCh and GCh compared to other methods for soil improvement since it is recycled from waste materials.
7. Recycling of waste materials such as MCS can enhance the environment and reduce pollution.

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Assessment of Composite Materials in Civil Engineering Applications

M. Rizwan Akram[1]

Abstract

To meet the needs of the engineering, composite materials in the form of polyester resins are used to produce structural parts such as roof panels, pipes, kitchen, bath, and shower trays etc. in civil engineering applications. Unsaturated polyester resin (UPR) is one of the main raw material chemicals available in liquid form. UPR has linear polymer with ester bond along with the double bond due to the dibasic acids. The study is carried to develop a constraint classification method for the assessment of various based UPR chemicals. The subject paper is unique in its category as it explains the different kinds of UPR based on various factors, summarize their costs and performance as a comparative parameter. Additionally, UPR in various civil engineering applications are explained in detail. It is believed that this study will emphasize the importance of UPR as smart, cost effective, and eco-friendly materials for the civil engineering applications. The development of this research will increase the reliability status of this world to a higher level.

Keywords: Unsaturated polyester resins, Structural material, Composite materials.

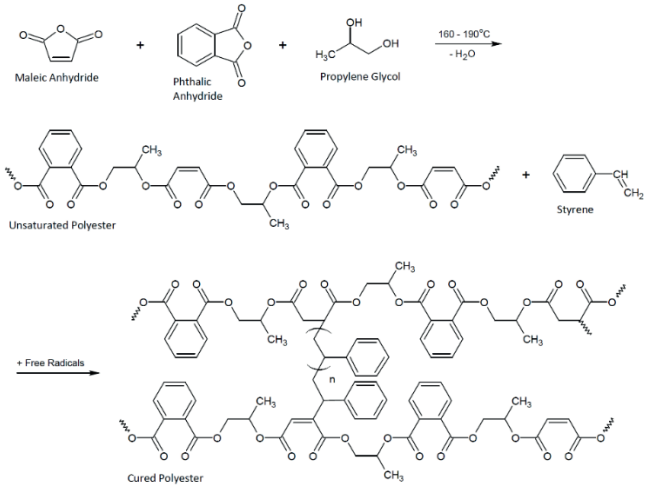
Discipline: Civil Engineering.

Introduction

In thermoset moulding resins, UPR are classified as third largest with respect to their applications. Their manufacturing process include the condensation of a diol that is mixed with saturated and unsaturated anhydrides. The condensed product is self-raw material of high reactivity, and it makes a durable structure by cross linking with monomer such as styrene as shown in Figure 1 [1-2].

[1] PhD. Graduate, Civil Engineering Department, Gebze Technical University, Turkey

Figure 1: Chemistry of UPR resin



Source: Unsaturated polyester resins in US patent 3,347,806 (Chemische Werke Albert) and 4,029,848 (Dow Chemical).

UPR in civil engineering applications are widely used from home appliances to the transport networks [2]. Sometimes, UPR is also used as replacement element for civil engineering materials [3].

Therefore, a proper background for UPR composition is necessary to understand. For this, a strong knowledge of chemistry is required as perquisite for its proper application in civil engineering industry [3]. There are number of research literatures available where most of research impacted on the use of UPR as one key element in their research works [4-8].

The main objective behind this study is to briefly explain the UPR as composite materials in civil engineering applications. The subject paper is unique in its category as it explains the various types of UPR based on different factors, summarize their costs and performance as a comparative parameter. Additionally, UPR in various civil engineering applications are also explained in detail.

It is believed that the results of this study will emphasize the importance of UPR as smart, cost effective, and eco-friendly materials for the civil engineering applications.

Classification of Unsaturated Polyester Resins (UPR)

UPR can be classified based on acid types, costs, and performance in the applications.

Classification Based on Acid Types

UPR resins can be categorized based on the type of acid they included in them [9]. Here below is the list of various UPR resin types based on their acid nature.

Table 1: various UPR resin types based on their acid nature

Type	Main Acid	Abbreviation
1	Ortho phthalic	ORTHO
2	Tere phthalic	TERE
3	Dicyclopentadiene	DCPD
4	İsophthalic	ISO
5	İsophthalic – Neopentyl Glycol	ISO/NPG
6	Vinyl ester – Bisphenol A	VE

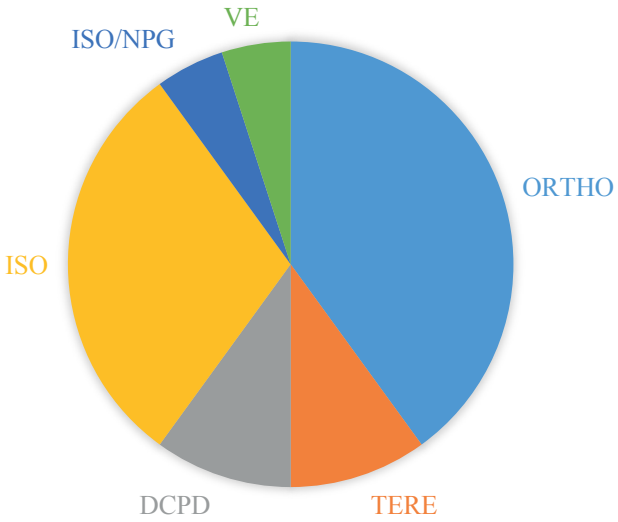
Source: (Unsaturated Polyester Resin for Specialty Applications)

Ortho resins offer a cost/performance advantage with excellent mechanical properties and secondary bonding characteristics. Iso resins provide improved chemical, heat, and moisture resistance as well as higher tensile properties. DCPD can be used as the primary base of a resin formulation or be blended with Ortho or Iso resins to enhance properties. Ortho, DCPD and Ortho/DCPD blends are also referred to as General Purpose (GP) resins because of the variety of applications in which they can be used. DCPD or Ortho/DCPD blends have become increasingly popular in open moulding because the DCPD component helps create a better cosmetic finish with less print-through and distortion on finished parts. The use of DCPD in resin formulations also allows resin producers to reduce styrene levels even as low as 30% thus reducing styrene emissions for manufacturers.

Classification Based on Costs

Based on cost, Orth phthalic polyester resins are widely used, following isophthalic, tere-phthalic, dicyclopentadiene, isophthalic – neopentyl glycol and vinyl ester – bisphenol A as shown in Figure 1.

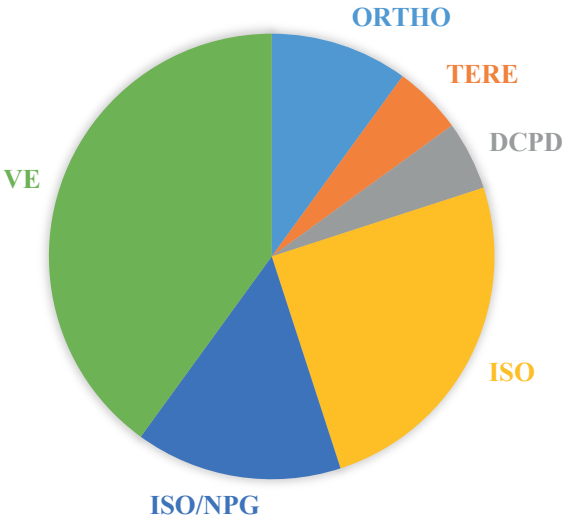
Figure 1: Classification Based on Costs



Classification Based on Performance

Based on performance assessment, vinyl ester – bisphenol resins are widely used, following isophthalic, isophthalic – neopentyl glycol, Orth phthalic polyester, tere-phthalic, and dicyclopentadiene as shown in Figure 2.

Figure 2: Classification Based on Performance



UPR in Civil Engineering Applications

From the recent years, UPR is widely used in most of civil engineering applications summarized as below.

Casting

UPR in casting purpose applications are used as bathtubs, wash basins and kitchen countertops. The reason behind the preference of UPR in casting is due to its suitability for artificial marble and smooth solid surface processing as shown in Figure 1. The other advantage is due to its high filling capacity and very lower shrinkage values. UPR is also used due to economical availability and its use leave a shiny and smooth surface on the final product.

Figure 3: UPR in casting application leave elegance appearance

Engineered Natural Quartz Stone (Breton Technology)

It is viable to make unique countertops, floors, and veneer materials with engineered stone applications. Resins of this class are specifically designed for quartz filled, natural composite stone constructions and Breton stone technology uses as shown in Figure 4.

Figure 4: UPR in Engineered Quartz Stone (Breton Technology) Application.

Filament Winding

Glass-fibre lamination is applied on to a turning spindle with resin. Moving spindle comprises of a steel ensemble which turns in the axial direction skidding over ball bearings. Pipes are made on this steel ensemble spindle incessantly. It is feasible to make pipes of different diameters with this procedure. This production practice has three primary phases. Raw material consuming phase, curing phase, and cutting phase. First, a release film (e.g., UPR film) is rolled onto spindle, followed by a surfacing mask. Glass roving, chopped glass material, sand aggregate and UPR are applied all together on the rotating spindle. After usage of raw materials, pressure spins aid to release trapped air inside the shield. After curing, final product is cut down into the preferred segments.

Figure 5: UPR in filament winding application.

General Purpose (GP Applications)

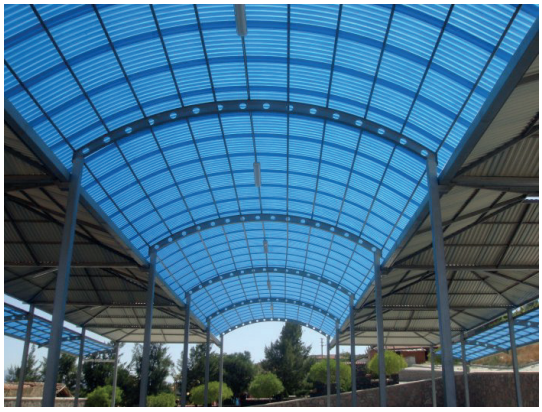
UPR in GP applications can be used both as hand lay up and spray up methods. The main application area includes air wind turbine blades, sliding water parks, buried continuous pipelines, construction of various building elements, transportation, and industrial units as shown in Figure 6. The reason behind the preference of UPR on other chemicals is due to its rapid wet out properties, excellent mechanical behaviour with good rigidity and dimensional stability.

Figure 6: UPR in gp applications.

Continuous Laminating

This is technique used in civil engineering to make flat, grooved, colour and transparent sheets at a rate of high production speed. The application is specially designed to manufacture roof slabs with sun lightening system, commonly used in shopping malls, play stadiums, libraries etc. as shown in Figure 7. The UPR in these applications is also used to manufacture foam sandwich panels, truck front panels, refrigerated panels of vehicles and RV panels.

Figure 7: UPR in continuous laminating applications.



SMC and BMC Applications

UPR are used as SMC and BMC applications in the fields of park equipment, electric boxes, electrical and thermal composite parts, plastic insulation boxes, and transformed insulation elements etc as shown in Figure 8.

Figure 8: UPR in SMC applications.

Acrylic ABS Backup Applications

UPR as acrylic is used to manufacture bathtubs, shower basins and jacuzzi trays as shown in Figure 9. These type of UPR have high filling capacity and can absorb filling materials such as calcite etc. up to 40% - 60% inside them.

Figure 9: UPR in acrylic ABS backup applications

Pultrusion Applications

Pultrusion is a continuous procedure selected in manufacture of materials with special mechanical properties in one direction. For example, structural profiles, rebars, posts and pipes of low diameter are manufactured with this construction method. UPR, with its high reactivity and chemical resistance is desired for production of gratings and structural profiles. UPR is also desired for production of rebars and profiles along with its applications in roadside delineator posts.

Figure 10: UPR in pultrusion applications

High Chemical Corrosion Resistance

The one of the best properties of UPR is their application in their chemical corrosion resistance

and handling of high temperature. Most of their applications are in the manufacturing industry of pipes, chemical storing tanks, spray banks, swimming pools, chimneys for petrochemical companies, power plants, marine automotives, and concrete flooring as UPR. An example of UPR in the application of chemical resistant tank is shown in Figure 11.

Figure 11: UPR in high chemical corrosion resistance applications.

Conclusions

In this study, an overview related to UPR application in civil engineering is explained. From this study, it is concluded that UPR is one of the smart, cost effective, and eco-friendly material for the civil engineering applications. Ortho resins offer a cost/performance advantage with excellent mechanical properties and secondary bonding characteristics. Isophthalic UPR offer enhanced chemical, heat, and moisture resistance as well as higher tensile properties. DCPD UPR can be used as the primary base of a resin formulation or be blended with Ortho UPR or Iso UPR to enhance properties. Ortho, DCPD and Ortho/DCPD UPR are also referred to as General Purpose (GP) resins because of the range of uses in which they can be used. DCPD or Ortho/DCPD UPR have become increasingly popular in open moulding because the DCPD UPR component facilitates to create a better aesthetic finish with less print-through and warp on completed parts. The use of DCPD in resin formulations also allows resin producers to reduce styrene levels even as low as 25% - 30% thus reducing styrene emissions for manufacturers.

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Prediction of Groundwater Level Using ANN Models Employing the Meteorological Parameters

Zulfiqar Ali[1],

Irfan Khan[2]

Dr. Mansoor A. Baluch[3]

Hammad Raza [4]*Qaiser Mehmood*[5]

Abstract

Groundwater levels are dependent upon the below soil strata and climate conditions. Over consumption of water is causing the lowering of the GW table. In Pakistan, due to over extraction of water, most of the regions are totally dry even in temperate areas no water for crops.

In this research, GW levels of diverse stations are monitored by meteorological parameters. Based on stations climatic parameters data to instruct the ANN prototype for the prediction of groundwater levels, Pearson's Correlation Coefficient (r) is used to achieve the future levels. Area of research was Dera Ismail Khan, Bannu and Peshawar meteorological stations. According to tube wells, area of stations is divided into different regions to obtain the better predictions. MATLAB Neural Network Toolbox is employed to teach the ANN model. The model is comprised of network architecture, neuron numbers, hidden layers, validation, and testing. Coefficient of determination (R), MSE (Mean square error) and MAE (mean absolute error) are basis of optimal network of ANN architecture which will predict the future groundwater levels.

Obtained results predicted that at single, double, and triple input of data, water levels were declining with limited recharge. For DI Khan station a decreasing and increasing trend was observed which presented that recharge was available. In Bannu station, a huge difference was

[1] PhD Research Scholar, Cukurova University, Adana, Civil Engineering Department
[2] Assistant Engineer, Hazara University, Mansehra, Building & Works Department, Pakistan
[3] Chief Operating Officer, Punjab Higher Education Commission, Punjab Pakistan
[4] Lecturer, University of Engineering & Technology, Taxila, Civil Engineering Department
[5] PhD Research Scholar, Cukurova University, Adana, Engineering Geology Department

observed from the center line. It predicted that no recharge just dropping of table. As a while, in Peshawar station, recharge was available at some elevation outside the metro political areas. At inputs of data for single, double, and triple all forecasting levels were in acceptable limits.

Keywords: Artificial Neural Network, Mean Square Error, Soil and Water Assessment Tool, Depth to Water Table, Groundwater Table

Discipline: Civil Engineering (Science & Engineering)

Introduction

Glaciers and polar ice caps are resources of water on earth, but groundwater is extensively spread source of water. So, groundwater is used for all purposes like domestic, agronomy and industrial, but the agronomy is major consumer for irrigation. Which utilizes more than 80% of consumed water. To manage the levels of underground water, accurate and comprehensive management system is required. Multiple factors which influence the groundwater levels mainly affect the substrata levels, which are supply needed, sea waves, quake, volcanic eruption, land collapsing, upper strata streamflow disparities and meteorological parameters like rain, wind speed and temperature [1].

To approximate the groundwater levels, the effectual implemented approach is influence of meteorological parameters. Parameters like pressure which causes land subsidence above or below the strata and generate level disturbances in confined and unconfined aquifers as while wind which affect the levels on the top surface and follow the patterns of vegetation cover over the top strata. Other parameters like rainfall and frost have same influence over the groundwater levels leading to the evapotranspiration which can affect the GWT levels. Precipitation factor is widely connected with levels of substrata flowing water. Percolated water from top surface to lower groundwater table raises the level. But percolation is dependent upon the soil strata and grainsize available in the specific region. Moreover, it is dependent upon the capacity available for storing the water. Heavy precipitation with higher seepage rate or vegetation cover also affects the groundwater flow in substrata confined and unconfined aquifers [2, 3].

Up to now, multiple in numbers of researchers have evaluated new approaches and techniques to determine the groundwater levels with respect to meteorological parameters or with real time monitoring of wells. So, majorly two approaches were adopted by the researchers one is empirical approach based on the data available and second approach is physical numerical

models to predict the levels of flowing aquifers. Another approach in terms of empirical method is time to time monitoring of groundwater flow. First approach which is physical numerical based approach has multiple limitations like through physical approach real time accuracy is unattainable as cannot remove the inevitable divergences. So, developed model and real time simulations have accuracy and precision errors. In continuation with this, second technique empirical models run with some limitations. Because data collected can be with errors and misleading positioning. So, to monitor the groundwater levels with dynamical conduct of hydrological structures which alters with moment in time. Now a days, several mew advances and techniques are being sourced in the field of hydraulics and water resources are ANN, GP, ANFIS and SVM which make issues workable in the calculations [4, 5].

To cope the demand of an efficient water management in hydrological research, the best and comprehensive technique adopted by researcher is ANN (Artificial Neural Network). ANN is the diversified tool which can predict different situations and characteristics based on different logics and variables. ANN techniques which are based on logics can be used for smaller areas with limited inputs and for diversified composite fields to model them on multiple logics to predict the properties and oscillations of groundwater altitudes. This tool is employed for the prophecy of potentiometric surface altitudes. According to researchers, ANN is best tool for the prediction and anticipating of groundwater heights in an unconfined aquifer. Moreover, ANN can be employed with hybrid numerical configuration for groundwater flow modeling setting the limitations of constraints over it [5, 6].

To solve or to predict the real groundwater related issues and management then multi-objective optimization with ANN model can be used mainly to predict the altitudes and flowing curves of saturated and unsaturated porous and nonporous strata. The hybridization of ANN with other optimization tools can be used for optimization of results in unsaturated regions to predict the groundwater levels based on multiple logics. Moreover, this technique can be employed to probe the human being activities which affect the substrata groundwater levels mainly population growth or construction of high-rise buildings. According to conclusive results of researchers most of them favor the use of SVM technique over the ANN to solve the issues of hydrology. But major portion of these researchers support the ANN tool because it can be employed for real time to even based modelling. They name it “Black Box” over the properties of linear and non-linear modelling of properties. Essential element of ANN model is that it

detects the chronic modifications and repaired models in the complex natural procedures [1, 7].

To predict the levels and to manage the substrata water resources, a complete set of hybridized ANN model can be used which employ large range of inputs to calculate the results. Multiple techniques like Artificial Intelligence (AI), Fuzzy Inference System and adoptive networks hybrid with ANN (Artificial Neural Networks), PSOANFIS (Particle Swarm Optimization) and SVM (Support Vector Machines) to predict the concentration of daily precipitation established on variables like temperature (maximum and minimum), wind speed, solar radiation concentration, relative humidity, and elevation of region. Data collection mainly meteorological data and hydrographic data which are basic parameters for the planning and management of projects related to groundwater or water resources. Data collection is sophisticated job because recorded data is used for the planning of hydrological systems. So, missing data like recording error, extreme weather conditions, instrumental errors or failures lead to miscalculations and future challenges. All the recorded data is firstly analyzed and checked the meteorological patterns then computed in ANN coding sheets to compute the results. To compute the missing data with techniques of interpolation, one technique is Non-linear Principal Component Analysis which leads to ANN. ANN can be used with multiple inputs and output configurations to predict the levels altitudes and flow results. Data Mining is basic thing to build the statistical correlation between input parameters and output results [8, 9].

ANN is best tool which can be used for minor to major analysis like weekly prediction and estimation to yearly or decade estimation and calculation of results in water resource management systems. Exhaustive farming is also tapping gravity on groundwater table. In the past, farmers utilized to grow one crop in a season. Currently they harvest three or four crops in a year which needs intense water. So, the demand of groundwater has been increased and there is need to manage this precious resource. Rainfall is a complex phenomenon occurring on the earth and groundwater level is proportionate to the rainfall. Some other factors like, climate change, soil characteristics, water bearing strata and human activities also play a vital role in groundwater variations.

In this proposed research, an attempt has been made to nexus groundwater level along by meteorological factors (wind, Rainfall, temperature, solar radiation, humidity, and elevation of the area) by using soft computing tool, Artificial Neural Networks (ANN) and to develop future prediction prototypical for the groundwater of the study area.

Materials and Methodology

Study Area: The area for research was Khyber Pakhtunkhwa (KPK) three metrological stations Bannu, Dera Ismail Khan, and Peshawar. Selection was based on the plain regions and mountainous hikes. Specifically, in KPK province, these three stations contain agricultural, mountainous, and residential areas. Dera Ismail Khan is the upstream basin of river Indus with a Longitude 70.78º and Latitude 31.92º and 165m above sea level. Bannu is upstream of river Kurram. So, this station lies between Latitude 32.59º and Longitude 70.36º with a 382-meter elevation above the sea. Peshawar is a Kabul River downstream ranges between Latitude 33.49º and Longitude 71.31º and elevation is 331-meter above sea level.

Collection of Data: The data of Groundwater readings were obtained from the Public Health Engineering Department and Irrigation Department of KPK. The specified period was 2002-2018. Ignoring the private tube wells and their numbers.

The **Climatological data** was taken from the SWAT (Soil and Water Assessment Tool) website (https://globalweather.tamu.edu/). Two-decade data from 2000 to 2018 including selected parameters (Max. Temperature, Min. Temperature, Rainfall, RH (Relative Humidity), Wind Speed and Solar Radiation were taken from the SWAT internet site for different meteorological conditions. ANN model data bank is comprised of pre and post monsoon by taking arithmetic mean average of first six and last six months of year for all parameters of 12 stations (table 1).

ANNs follow the patterns of dominant nervous structure of human brain and animal genetic Neuronal Network. Figure 1 is depictive of how ANN is employed to accomplish assessments with specific tier and preference. Further, Equation-1 is defining the simulation of decisive amount by indicating the correlation between the seams.

$$O = f\,\Sigma x_i w_i + b \qquad (1)$$

Table 1: List of 12 Meteorological Station

Sr. No	Station No.	Longitude	Latitude
1	Weather data-DI Khan_1	70.9019	31.8626
2	Weather data-DI Khan_2	71.3254	32.0238
3	Weather data-DI Khan_3	71.5562	32.3647
4	Weather data-DI Khan_4	71.9837	32.6321
5	Weatherdata-Peshawar_1	71.57849	34.008

6	Weather data- Peshawar_2	71.8754	34.417
7	Weather data- Peshawar_3	72.07349	34.721
8	Weather data- Peshawar_4	72.4625	34.863
9	Weatherdata-Bannu_1	70.6455	32.9910
10	Weather data- Bannu_2	71.5349	32.0010
11	Weather data- Bannu_3	71.8345	32.0420
12	Weather data- Bannu_4	72.0035	33.3370

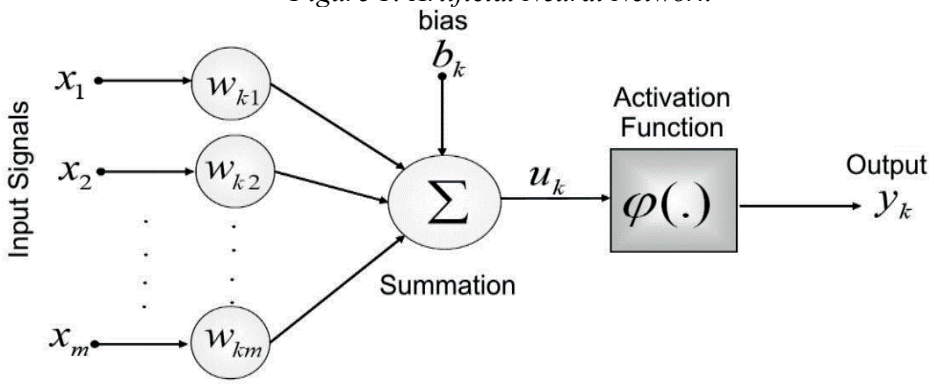
Equation 2 is defining the Pearson's correlation(r) and connection between two factors.

$$r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{n(\Sigma x^2) - (\Sigma x)^2}\sqrt{n(\Sigma y^2) - (\Sigma y)^2}} \qquad (2)$$

By utilizing the equation 3, it is evident to stabilize the parameters within the applicable upper and lower limits [10]. So, all the parameters were standardized among the $[0.1 - 0.9]$ rather than $[0 - 1]$.

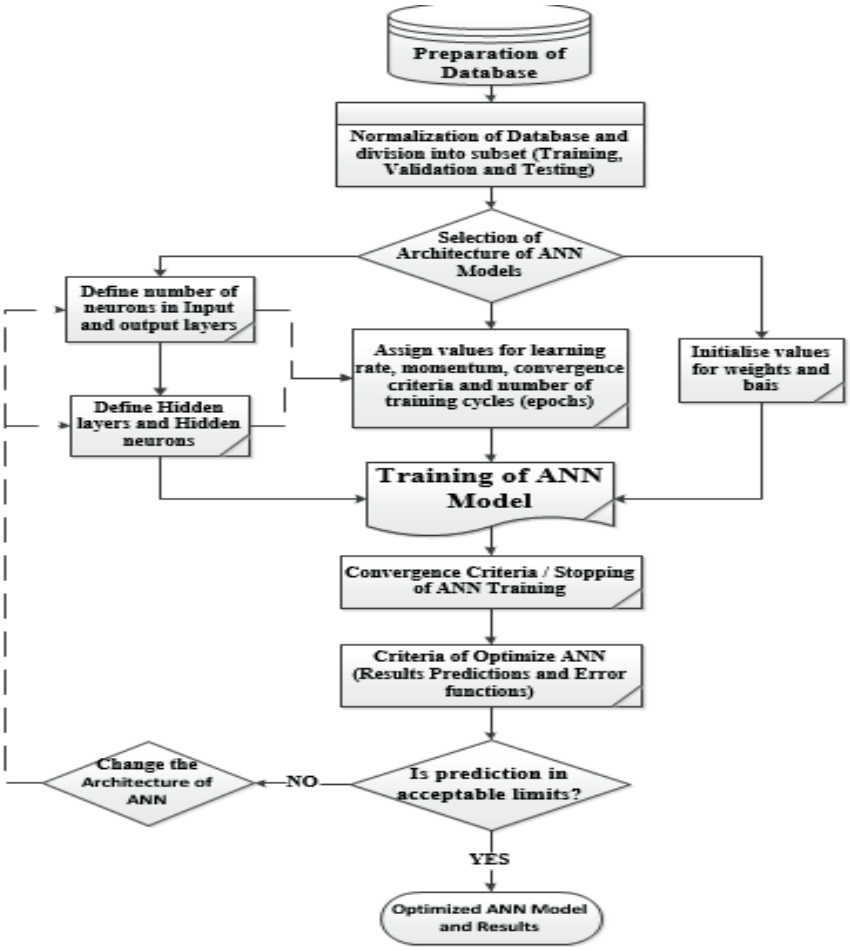
$$x = \frac{0.8}{x_{max} - x_{min}} + \frac{(0.9 - 0.8x_{max})}{x_{max} - x_{min}} \qquad (3)$$

Figure 1: Artificial Neural Network



In this research, MLFNNs (Multilayer feed-forward NNs) are assumed to be excellent solutions [11-13]. Where ANN is further implemented employing MATLAB for prediction of GWT levels based on input and output layers whereas hidden layers depends upon the ANN architecture as presented in

Figure 2. Figure 2: Flow to develop ANN

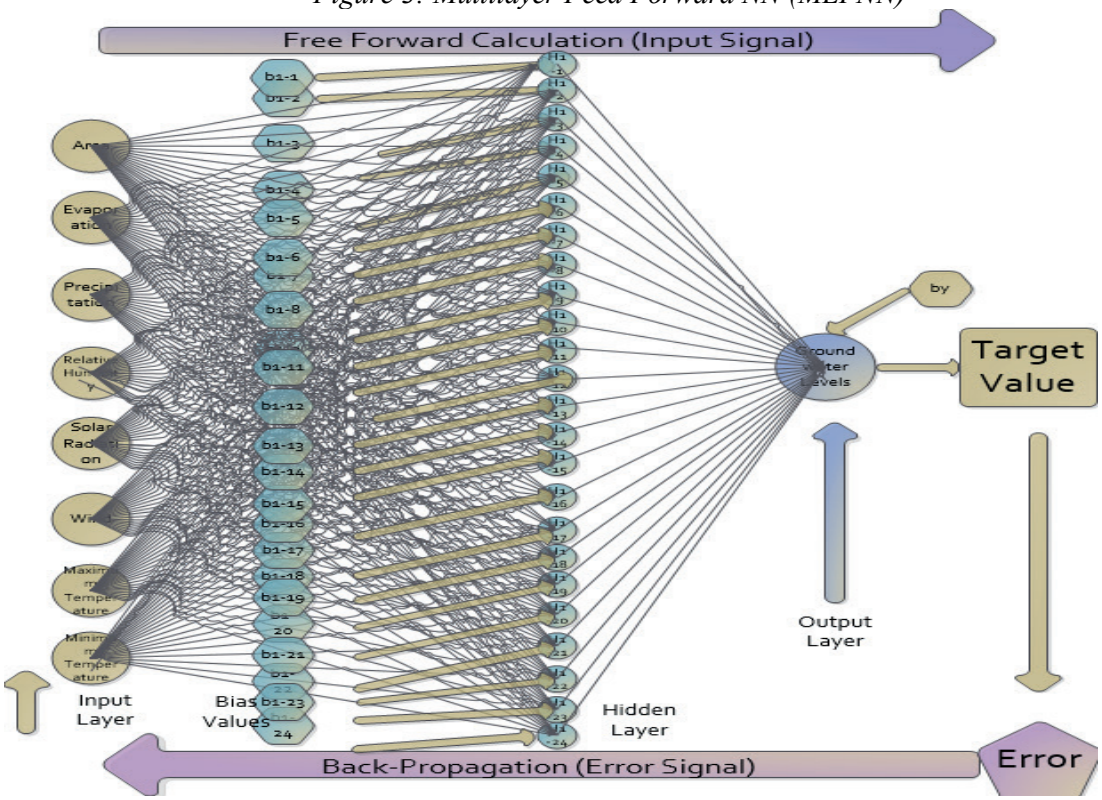


For the determination of Model performance, various activation functions between inputs, output and hidden layers are used as presented in table 2 [14]. Resultant error was determined by subsequent equation 4.

$$E(w) = \frac{1}{2}\sum_i [T^2 - O^2] \qquad (4)$$

Error generated by equation 4 was then reduced by reverse dissemination method. The aim is to revise the principles of loads which were primarily preferred. Following the yield principles, amended loads were applied in the ANN to attain more accurate forecasts which transform the consequences into diminished inaccuracies [15, 16].

Figure 3: Multilayer Feed Forward NN (MLFNN)



Architecture of ANN was determined by selecting the appropriate combination of parameters and depends on the type of problem associated and it is governed by trial-and-error method. To expand the architecture model of ANN, the database was distributed into three unique sub-sets depends on the percentage of data chosen for testing, training, and validation. **In the 1st sub-set:** 60% of the statistics was employed for training**,** 20% for the records testing and 20% for data validation. **2nd sub-set:** for training 70% statistics was chosen, for validation 15% records and for testing 15% numbers were chosen. **3rd sub-set**: 80% records for training, 10% statistics for validation and 10% records for testing. The main objective of choosing the diverse percentages of statistics for the training, testing, and the validation was to analyze the ANN model's functioning.

Table 2: ANN Architectural Model [14]

Model	Parameters (Input)	Obscured Neurons Numbers	Function (Input layer to Covered Layer)	Function (Covered layer to Output Layer)	Function (Shrouded layer to Obscure Layer)	Division of Data for Training, Validation and Testing			Output
						Training	Validation	Testing	
LT-8-H-1	*P, A, T-max, T-*	8,16,24	log sigmoid	-	tan sigmoid	80,70,60	10,15,20	10,15,20	$[D/w]$

	min, R.H, E, S.R, W								
TT-8-H-1	*P, A, T-max, T-min, R.H, E, S.R, W*	8,16,24	tan sigmoid	-	tan sigmoid	80,70,60	10,15,20	10,15,20	$[D/w]$
LTT-8-HH-1	*P, A, T-max, T-min, R.H, E, S.R, W*	8,16,24	log sigmoid	tan sigmoid	tan sigmoid	80,70,60	10,15,20	10,15,20	$[D/w]$
TLL-8-HH-1	*P, A, T-max, T-min, R.H, E, S.R, W*	8,16,24	tan sigmoid	log sigmoid	log sigmoid	80,70,60	10,15,20	10,15,20	$[D/w]$
LTTT-8-HHH-1	*P, A, T-max, T-min, R.H, E, S.R, W*	8,16,24	log sigmoid	tan sigmoid	tan sigmoid	80,70,60	10,15,20	10,15,20	$[D/w]$
TLLL-8-HHH-1	*P, A, T-max, T-min, R.H, E, S.R, W*	8,16,24	tan sigmoid	log sigmoid	log sigmoid	80,70,60	10,15,20	10,15,20	$[D/w]$

Results and Discussions

Selection of Best ANN Model

The subsequent performance criteria applied to select the best ANN models was: MSE (Mean Square Error), MAE (Mean Absolute Error) & Coefficient of Determination. In tables 3 for D.I Khan, Bannu & Peshawar respectively, ANN prototypes were devised for the training, validation and testing of each station [14].

Table 3: Based on the "R" value, the most excellent chosen ANN models [14].

ANN Model: D.I Khan					
ANN Models	***Percentage***	***Testing***	***Validation***	***Training***	***Overall***
LT-8-8-1	*(15%/15%/70%)*	*0.814*	*0.821*	*0.946*	*0.942*
LT-8-8-1	*(10%/10%/80%)*	*0.878*	*0.946*	*0.965*	*0.948*

LT-8-16-1	*(15%/15%/70%)*	*0.932*	*0.878*	*0.923*	*0.938*
LT-8-24-1	*(20%/20%/60%)*	*0.798*	*0.836*	*0.989*	*0.920*
LT-8-24-1	*(10%/10%/80%)*	*0.887*	*0.864*	*0.967*	*0.955*
TT-8-8-1	*(10%/10%/80%)*	*0.818*	*0.874*	*0.947*	*0.919*
TT-8-16-1	*(10%/10%/80%)*	*0.898*	*0.932*	*0.912*	*0.889*
TT-8-24-1	*(20%/20%/60%)*	*0.798*	*0.816*	*0.946*	*0.887*
TT-8-24-1	*(10%/10%/80%)*	*0.973*	*0.887*	*0.948*	*0.965*
LTT-8-8-8-1	*(20%/20%/60%)*	*0.823*	*0.838*	*0.958*	*0.923*
LTT-8-8-8-1	*(10%/10%/80%)*	*0.798*	*0.879*	*0.989*	*0.945*
LTT-8-24-24-1	*(20%/20%/60%)*	*0.882*	*0.871*	*0.934*	*0.931*
ANN Model: Bannu					
LT-8-8-1	*(15%/15%/70%)*	*0.814*	*0.821*	*0.946*	*0.942*
LT-8-8-1	*(10%/10%/80%)*	*0.878*	*0.946*	*0.965*	*0.948*
LT-8-16-1	*(15%/15%/70%)*	*0.932*	*0.878*	*0.923*	*0.938*

LT-8-24-1	*(20%/20%/60%)*	*0.798*	*0.836*	*0.989*	*0.920*
LT-8-24-1	*(10%/10%/80%)*	*0.887*	*0.864*	*0.967*	*0.955*
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TT-8-24-1	*(20%/20%/60%)*	*0.798*	*0.816*	*0.946*	*0.887*
TT-8-24-1	*(10%/10%/80%)*	*0.973*	*0.887*	*0.948*	*0.965*
LTT-8-8-8-1	*(20%/20%/60%)*	*0.823*	*0.838*	*0.958*	*0.923*
LTT-8-8-8-1	*(10%/10%/80%)*	*0.798*	*0.879*	*0.989*	*0.945*
LTT-8-24-24-1	*(20%/20%/60%)*	*0.882*	*0.871*	*0.934*	*0.931*
ANN Model: Peshawar					
LT-8-8-1	*(15%/15%/70%)*	*0.983*	*0.948*	*0.975*	*0.956*
LT-8-8-1	*(10%/10%/80%)*	*0.812*	*0.898*	*0.968*	*0.985*
LT-8-16-1	*(15%/15%/70%)*	*0.892*	*0.848*	*0.959*	*0.957*
LT-8-24-1	*(20%/20%/60%)*	*0.867*	*0.878*	*0.938*	*0.943*

TT-8-8-1	*(10%/10%/80%)*	*0.830*	*0.892*	*0.968*	*0.945*
TT-8-16-1	*(10%/10%/80%)*	*0.90*	*0.936*	*0.987*	*0.972*
TT-8-24-1	*(10%/10%/80%)*	*0.934*	*0.934*	*0.968*	*0.985*
TT-8-24-1	*(20%/20%/60%)*	*0.979*	*0.885*	*0.978*	*0.981*
LTT-8-8-8-1	*(10%/10%/80%)*	*0.872*	*0.929*	*0.987*	*0.956*
LTT-8-16-16-1	*(20%/20%/60%)*	*0.892*	*0.930*	*0.971*	*0.948*
LTT-8-16-16-1	*(10%/10%/80%)*	*0.901*	*0.884*	*0.979*	*0.959*
LTT-8-24-24-1	*(20%/20%/60%)*	*0.894*	*0.889*	*0.958*	*0.962*

Exceptional ANN model is based on values of "*R*" which is calculated from comparison among Testing, Validation, Training, and Overall inputs presented in figure 4(a) and 4(b).

Figure 4(a): Values of "r" paving ANN model selection

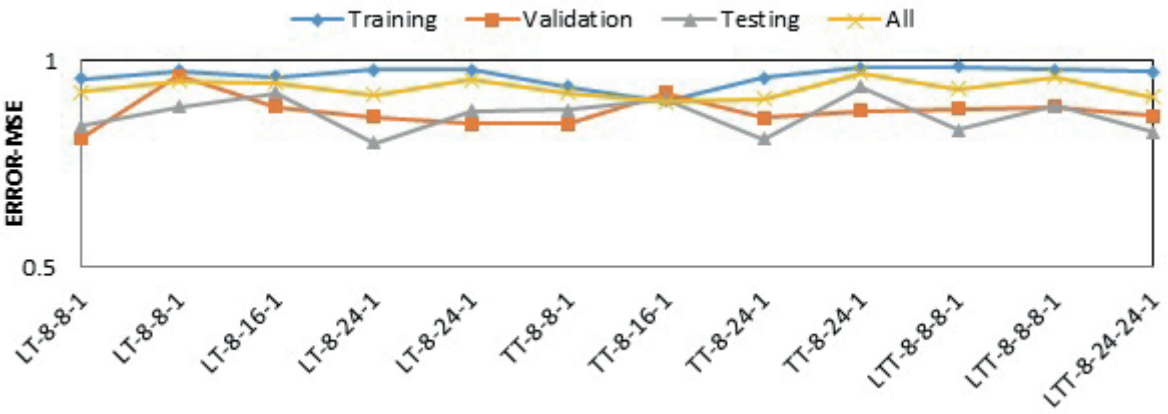
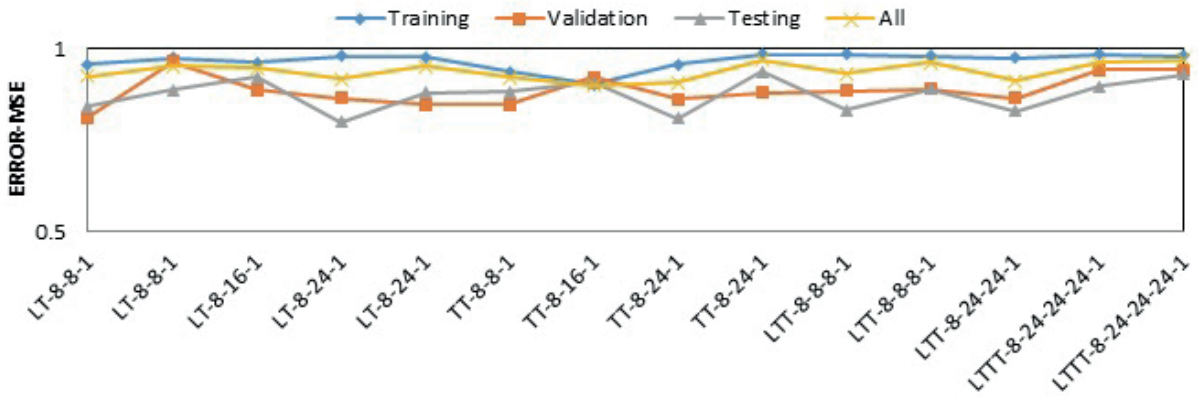


Figure 4(b): Values of "r" basis for ANN model selection



Optimistic ANN Model: Out of the best selected ANN model, model-8 (**TT-8-24-1**) and model-9 (**TT-8-24-1**) are chosen as optimistic ANN models for the DI Khan, Bannu and Peshawar cases respectively, built on MAE, MSE, and "R" values. Comparisons are shown in Figure 5(a) & 5(b).

"MSE" of excellent preferred ANN models to expand from the values 0.0023 to value of 0.0075 and the value of "R" increase from 0.90 to 0.97 for the DI Khan, Bannu and Peshawar. "MSE" diverse from 0.0021 to 0.0040 while "R" changes from 0.95 to 0.97.

Prediction Model: Predicted groundwater levels through optimized ANN models for Dera Ismail Khan, Bannu, and Peshawar metrological stations are developed for single, double, and triple inputs. So, presented in figures 6(A, B & C), 7(A, B & C), and 8(A, B & C) sequentially.

Figure 5(a): Assessment of best preferred ANN models based on values of MSE, MAE, and R values

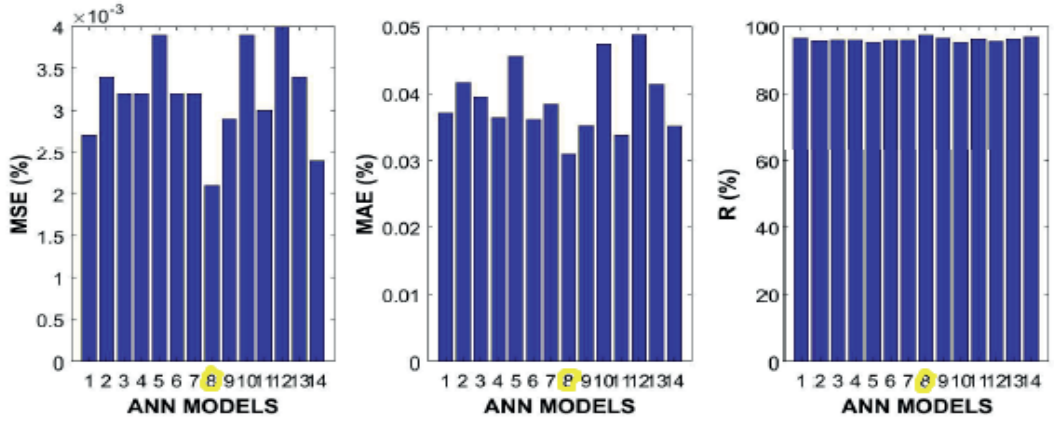


Figure 5(b Assessment of best preferred ANN models based on values of MSE, MAE, and R values

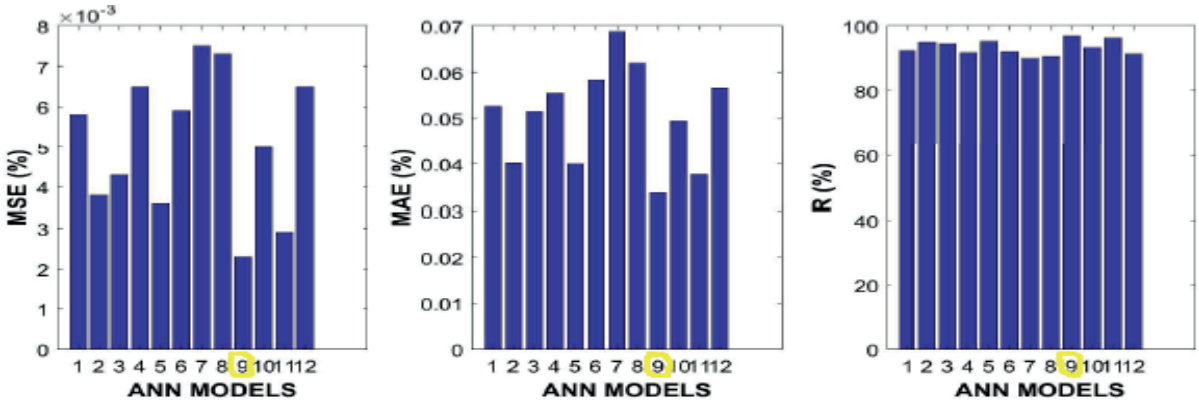


*Figure 6(A): Dera Ismail Khan Station (Training of data for **Single** Input)*

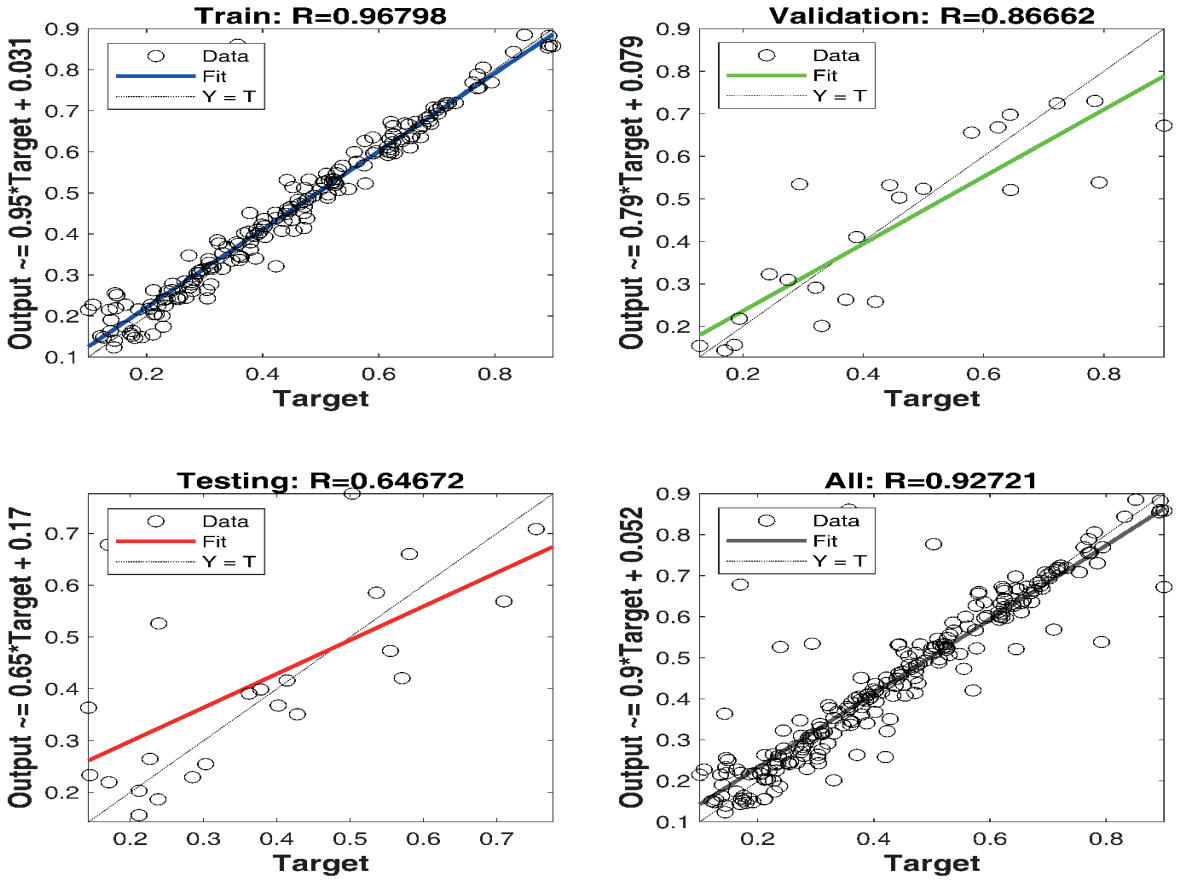


*Figure 6(B): Dera Ismail Khan Station (Training of data for **Double** Input)*

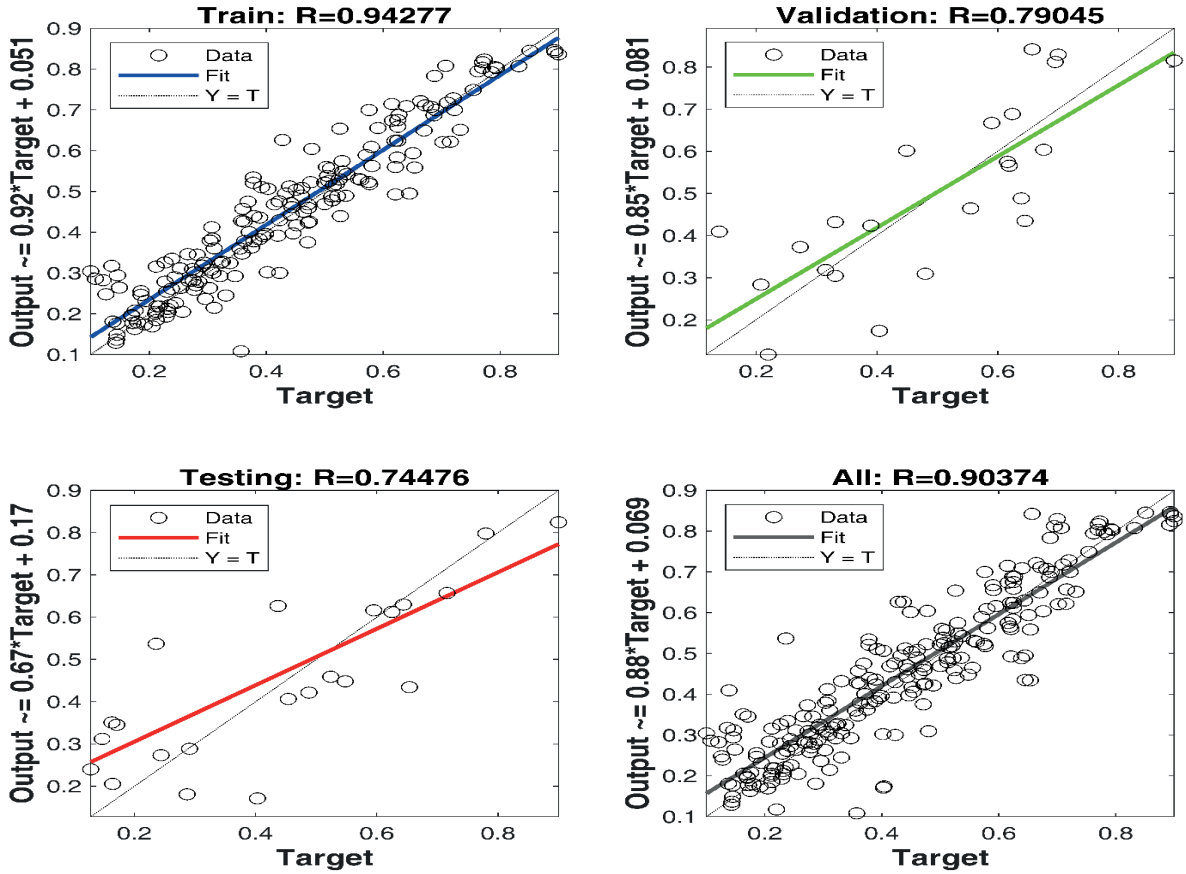


*Figure 6(C): Dera Ismail Khan Station (Training of data for **Triple** Input)*

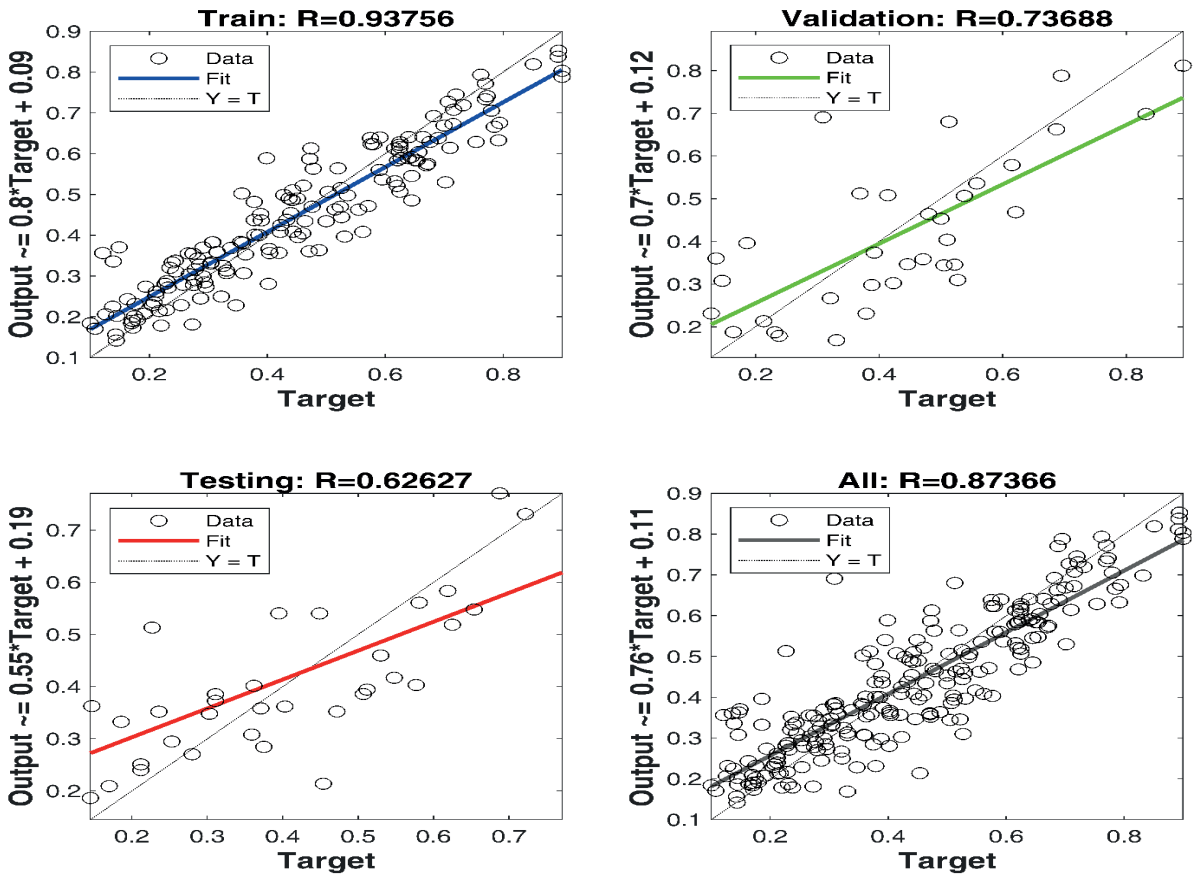


*Figure 7(A): Bannu Station (Training of data for **Single** Input)*

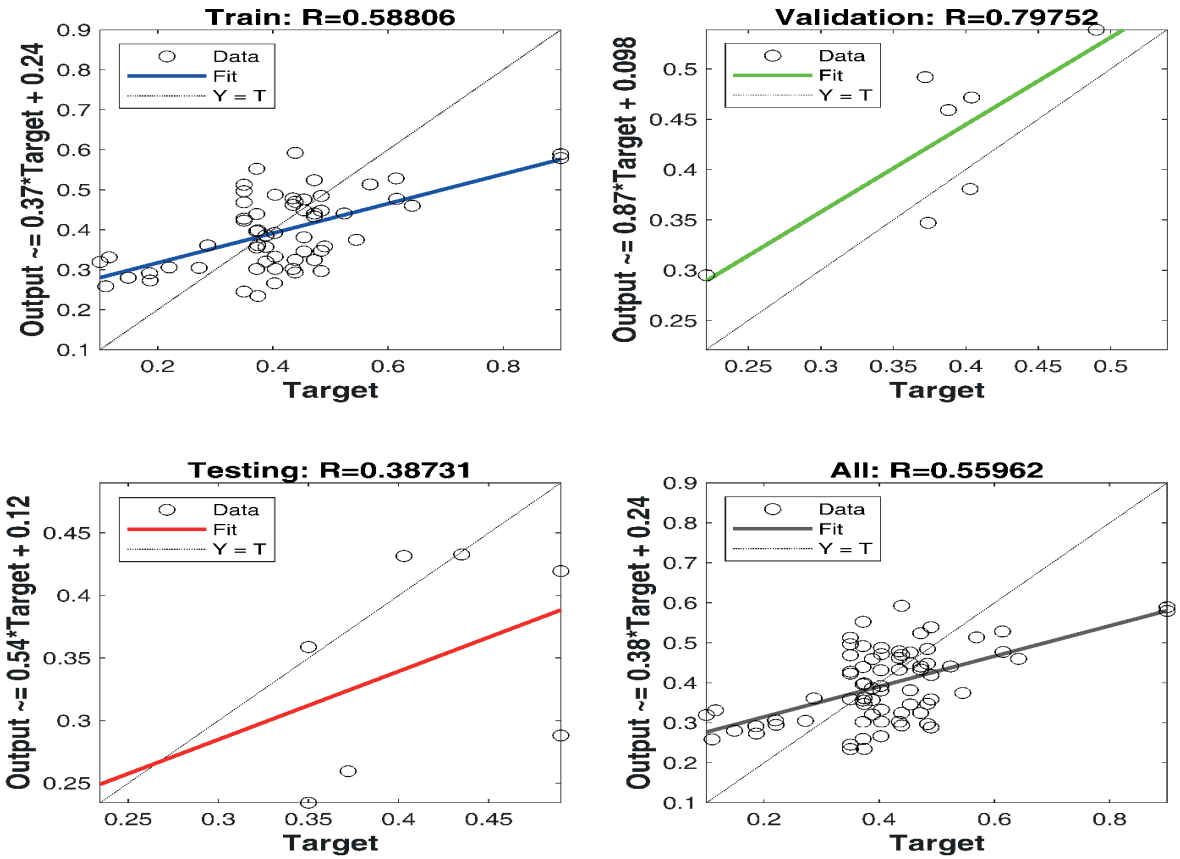


*Figure 7(B): Bannu Station (Training of data for **Double** Input)*

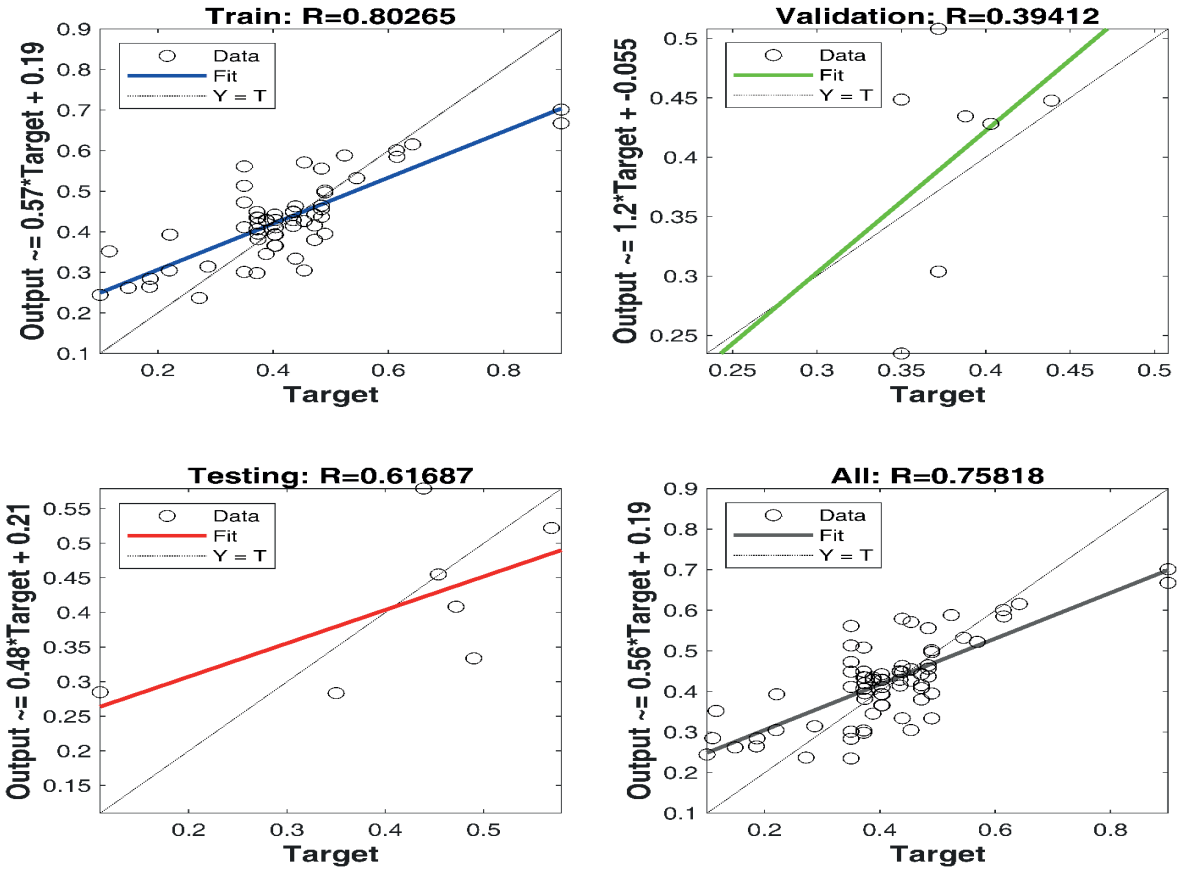


*Figure 7(C): Bannu Station (Training of data for **Triple** input)*

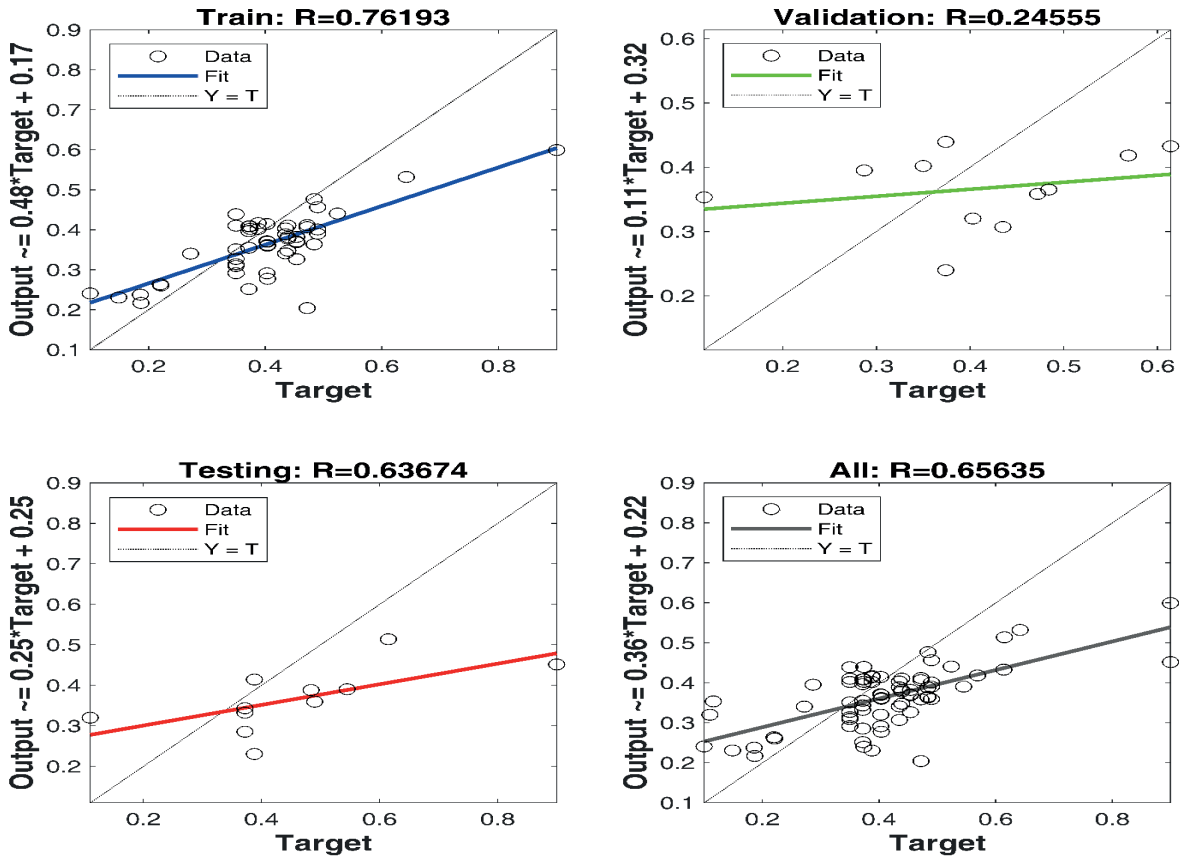


*Figure 8(A): Peshawar Station (Training of data for **Single** Input)*

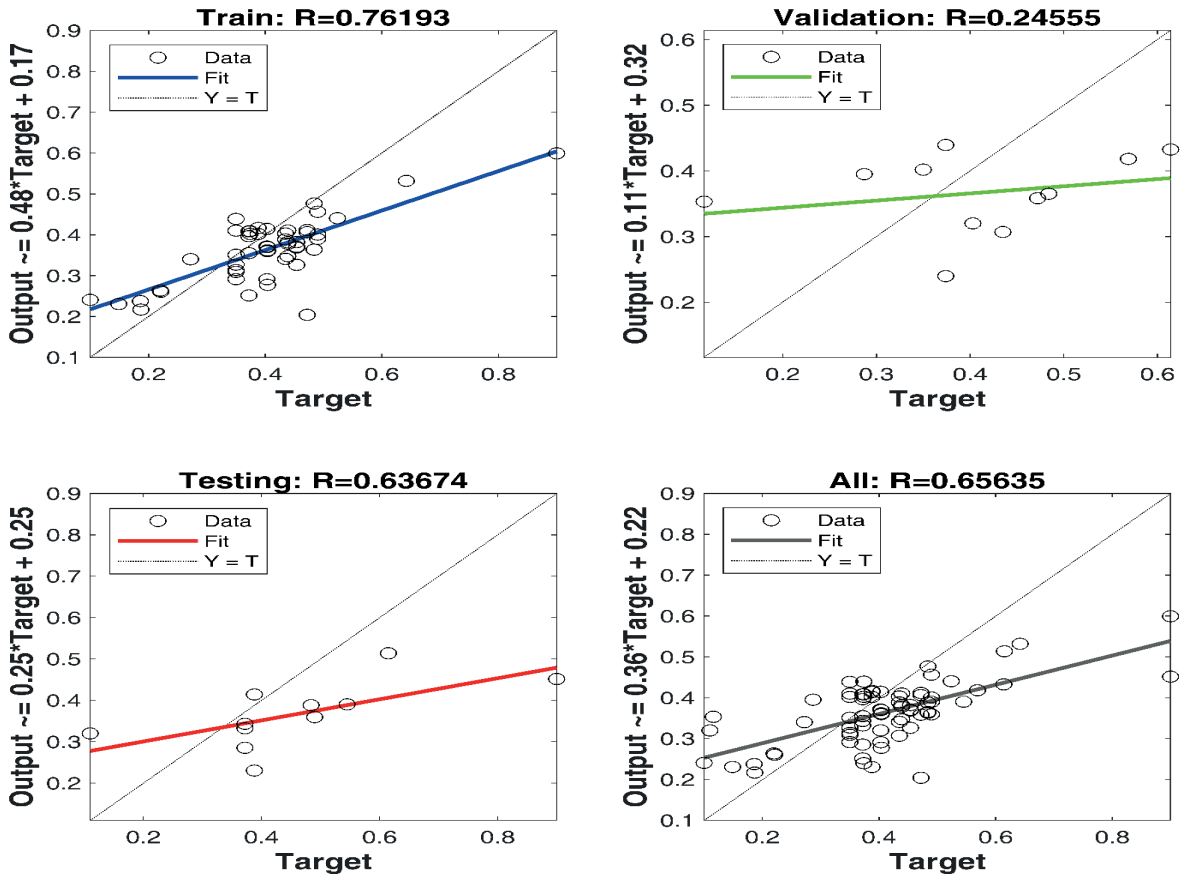


*Figure 8(B): Peshawar Station (Training of data for **Double** Input)*

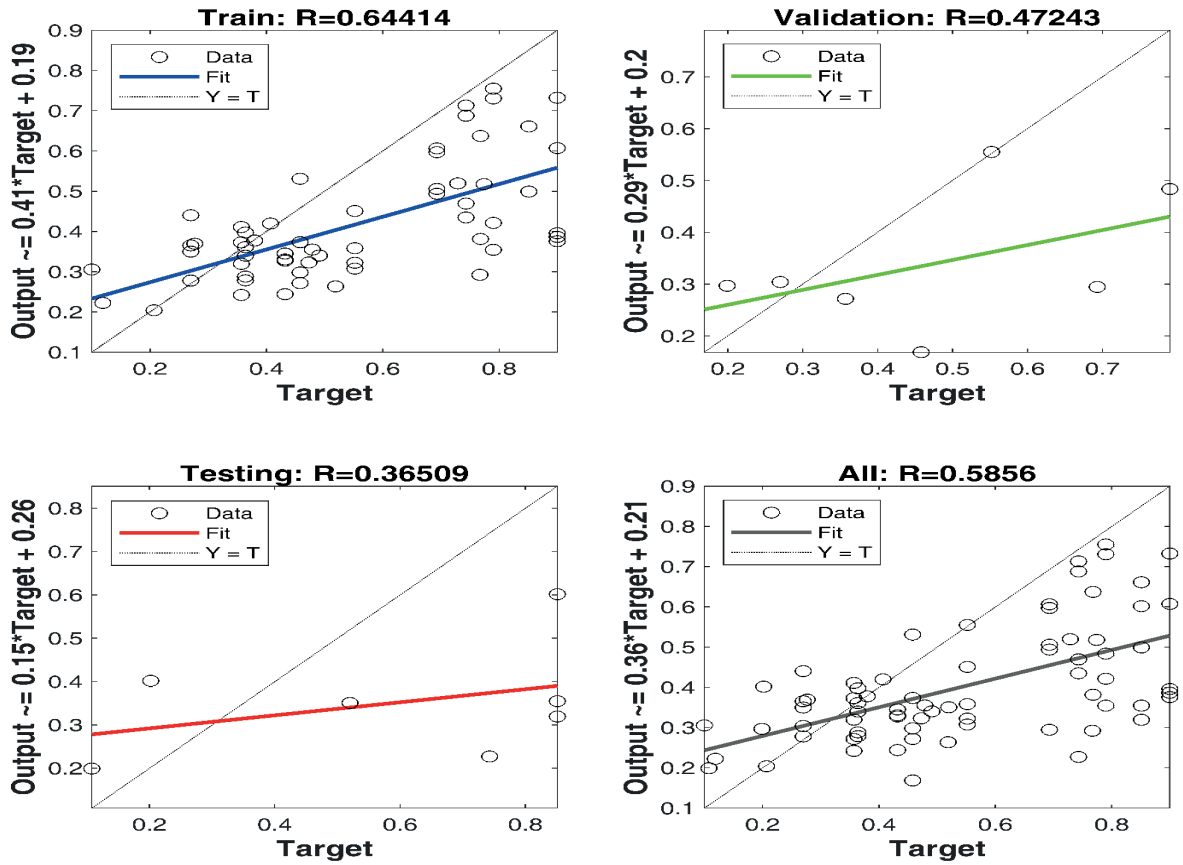
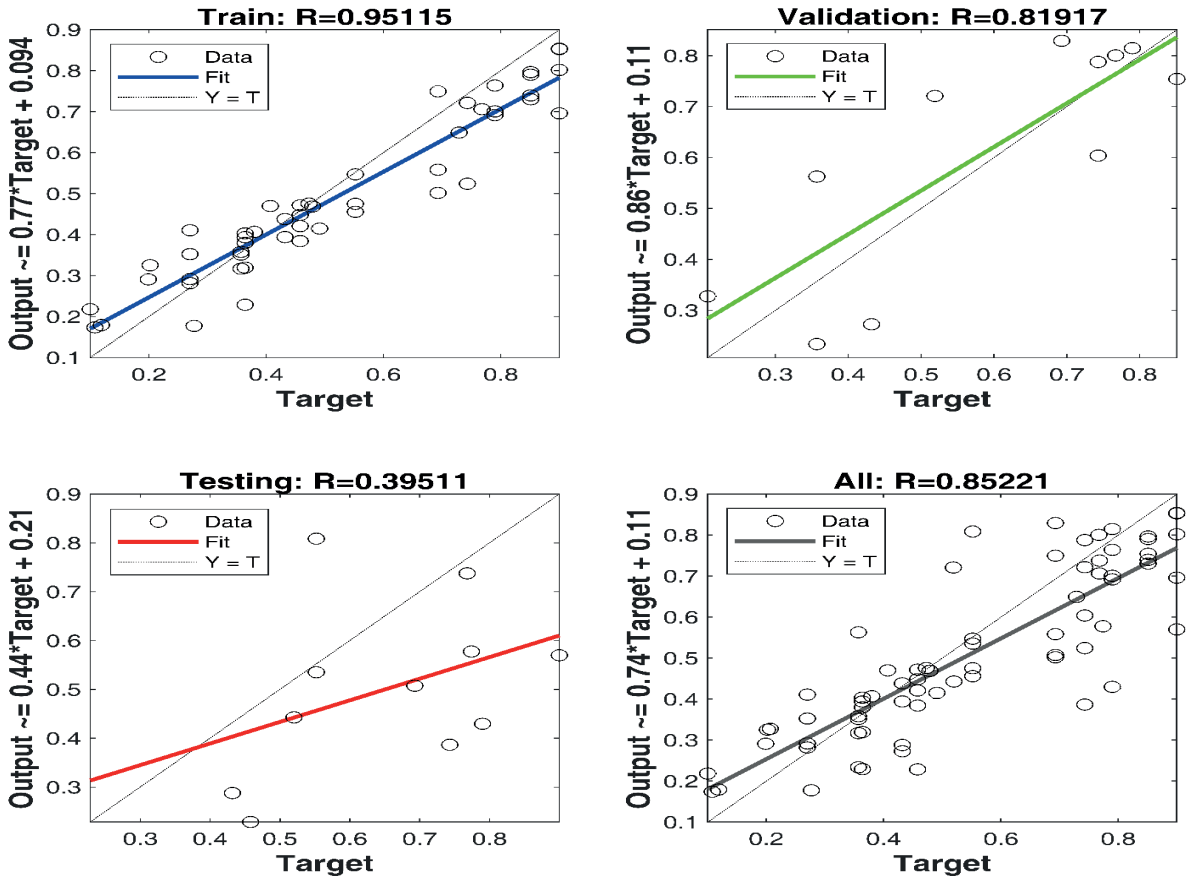


*Figure 8(C): Peshawar Station (Training of data for **Triple** Input)*



Discussion: Overall Groundwater Trends in the Dera Ismail Khan, Bannu, and Peshawar Stations

On the grounds of evaluation and analysis of the statistics for the monitoring points with continuous records, the levels of Dera Ismail Khan, Bannu, and Peshawar stations, it is predicted that parameters have a minute effect on the groundwater levels. The predicted results obtained through ANN also showing the same declining trend as observed groundwater level in the region. It is evident that at Bannu station meteorological parameters are not affecting the levels of groundwater. The level of GWT is dependent on parameters in areas of low elevation at Bannu station. For a while, Dera Ismail Khan stations have valuable relation between GWT and meteorological parameters.

Concluded that there was a reasonably good relation found between meteorological parameters with the groundwater levels and a good fit was observed between forecasted groundwater levels through optimal ANN model with the observed groundwater level. Regression analysis lines are predicting that water table levels and parameters are the best fit and affecting on the levels.

Moreover, for Peshawar station, the covered area is less as compared to other stations. Effective rainfall and humidity have no major effect on the groundwater level. It is evident that GWT levels are declining yearly and no recharge is found from these parameters. In a regression of 0.8522, a minutes correlation is found between levels and parameters.

Conclusions

- In this research work, a soft computing tool Feed Forward Neural System through a Levenberg-Marquard algorithm was applied to associate groundwater levels by meteorological constraints, and by use of different kinds of network architecture and training algorithm the model's accuracy was improved.
- This study concludes that for the DI Khan station there was a reasonably good relation found between meteorological parameters with the groundwater levels and a good fit was observed between forecasted groundwater levels through optimal ANN models with the experimental groundwater level.
- Based on the correlation developed among groundwater level with meteorological constraints, it is concluded that elevation of the area has a more pronounced impact on groundwater level as a comparison to other parameters, while the length of the area has very less effect.
- We can perform future forecasting of groundwater level in the study area by using predicted results obtained through optimal ANN models.

Recommendations

The approach to validate the results of Meteorological stations can be analysed further to get more accurate changing the MATLAB coding or adding more parameters mainly vegetation cover, soil moisture content and depth of groundwater.

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