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The Impact of Different Aggregate Types and its Composition on Resulting Concrete Properties Representing the Water Impermeability Level of Concrete for the Construction of White Boxes

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ABSTRACT

We understand the term 'white box' as a concrete structure in underground spaces, basements, or cellars, where it is necessary to consider the water impermeability of concrete or minimal changes in volume changes of concrete. These properties can be attained by creating the maximal compactness of the concrete composite when using the optimal combination of entrance components. The goal of this article is mainly to verify the effects of aggregate variety and its granulometric curve during the observation of volume changes and the water impermeability of concrete and another property, which are in white boxes constructions important. Granulometric curves of aggregates will be designed to ensure the minimal voids content of an aggregate, and the effect of the discontinuous granulometric curve will also be observed with respect of this property. During the design of the concrete mixtures, account was taken of a high amount of binding agent, which is used ensuring the higher compactness of cement stone was considered besides. For this reason, it will be verified also additive of finely ground limestone, thanks to which it is possible to partially replace a part of cement while maintaining the same properties of concrete. This method of design can lead not only to positive elimination of volume changes in a concrete mixture but also has a significant impact on dried concrete parameters, such as a high level of water impermeability.

Keywords Impermeable Concrete, Volume Changes, Granulometric Curve, Cavern Concrete

1. INTRODUCTION

The so-called 'white box' is a frequently sought alternative to secondary protective coats or various hydro-insulation systems during the construction of the foundations of buildings or underground building with the predicted occurrence of groundwater under pressure.

These structures are a suitable solution during the construction of underground parts of residential or public buildings, cellars, family houses, or buildings in general because they show property of high water impermeability.

'White box' is a term for reinforced concrete that has a hydro-insulation function, besides the structural function, without the need for using standard insulations. The hydro-insulation feature of a functional white box is ensured by several factors, such as correct construction and flawless design, but it is also appropriate for designing the composition of a concrete mixture. [1,2] For this impermeability concrete, it is necessary to have properties like low water absorption, high resistance to the penetration of groundwater under pressure, and minimal volume changes. It is well known that cement-based construction material is subject to various types of deformations, even in early stages. In terms of deformations that are not caused by mechanical activity, it is especially concrete shrinkage because of hydration processes. In the case of white box construction, cracks caused by shrinkage can significantly decrease the lifetime of such a construction; thus, it is necessary to approach concrete design in such a manner to reach the lowest possible shrinkage.

Figure 1. An example of an underground construction

Concrete construction is considered as water impermeable if it is able to resist water under pressure in such a way that no leakage or moist spots are visible on its air side. This feature is verified by testing the depth of the penetration of water under pressure according to ČSN EN 12390-8 [3] or by verification of water impermeability via the, HV" test according to the terms of TKP ŘVC ČR [4].

When selecting concrete components and preparing the concrete recipe, the required properties of fresh and dried concrete are considered. The selection of cement type should consider what environmental influences affect a concrete structure and the use of a massive or thin-walled structure. The parameters of aggregate, such as maximal grain size, granulometry, or grain shape, are equally important. Regarding volume changes, it is assumed that concrete is a three-phase composite material formed by a cement grout, an aggregate, and an interphase zone. The cement grout takes up approximately 24–30% of concrete volume. It consists of a cement binder, water, various types of additives and ingredients, air, and empty space.

This whole part is subject to shrinkage. However, coarse and fine aggregate are considered as stable concrete volume [5]. Thus, aggregate is considered as a component that plays an important role in the shrinking resistance of the cement grout. [6] It was verified in experiments that a cement stone compresses the surface of an aggregate with a force in a radial direction at the beginning of concrete hardening. Thanks to capillary forces, the shrinkage of cement stone and compression of the aggregate surface occur. The inflexion point of this dependency more or less corresponds with the change of the elastic deformation to the permanent – plastic deformation. The concentration of tensile stress around aggregate grains (transit zone) occurs between materials with different properties, which can lead to concrete failure. That is why the adhesion between the cement grout and aggregate is important.

The relation of volume changes of concrete with different types of aggregate, respective of the different size of the maximal grain and granulometric curve, will be verified in this experiment. The key properties regarding the high water impermeability of white boxes, such as water absorption and the depth of penetration of water under pressure, will be verified in this experiment.

2. MATERIALS AND METHODS

2.1. Continuous and Discontinuous Granulometric Curve

The main goal of this experiment was to verify the influence of various compositions of aggregates and the influence of a cement matrix on resulting properties such as the water absorption of concrete, the depth of water penetration, and volume changes, which are determined to ensure the high water impermeability of white boxes. In the first part of the experiment, recipes with a different type of aggregate were designed. The aggregate itself plays an important role during concrete shrinkage.

Some scientific studies show that for heterogeneous materials, such as concrete, failures most often occur in the weakest junction between the cement grout and aggregate, which is called the interphase zone. The concentration of tensile stress around the grains of aggregate (the transit zone) between materials with different properties can lead to concrete failure. For this reason, the adhesion between the cement grout and aggregate is important. Thus, the surface of an aggregate that affects the transit zone is an important factor. [7] For this experiment, two types of aggregate were used, namely crushed aggregate from Olbramovice and gravel from Žabčice. For both aggregates, recipes were designed with regard to using the continuous granulometric curve with the maximal grain of aggregate Dmax16 mm. Furthermore, recipes with a discontinuous granulometric curve, with the omission of fraction 4–8 mm and a maximal grain of aggregate Dmax22 mm, was designed in addition to the previous recipes. The resulting granulometric curves of aggregates with Dmax 16 mm and Dmax 22 mm were identical in order to compare the influence of the aggregate type on the monitored concrete parameters.

From the mineralogical point of view, the Olbramovice aggregate was granodiorite, and the Žabčice gravel was sedimentary psammite-type rock.

2.2. Use of Finely Ground Limestone

In the next part of the experiment, recipes with an additive of finely ground limestone were designed for this type of granulometric curve. The additive of finely ground limestone is widely considered as a non-active additive that does not actively influence the hydration process. It is used especially as a positive influence on the microstructure and improving the mechanical properties of a cement composite. However, some studies show the opposite and state that the presence of finely ground limestone slightly accelerates the hydration of cement (especially for clinker material C3S). The presence of limestone provides a more stable distribution of the pore size. This decreases the permeability of concrete and the transit zone between aggregate grains and improves the hydrated cement grout. If limestone grains are smaller than cement particles, pores between moisturising products fill up, which makes the cement matrix denser.

[8-10] Some studies point out that if the dose of limestone is lower than 15–20%, the workability of a mixture improves. At the same time, the compliance of appropriate fineness leads to a reduction of the concrete shrinkage.[11,12] In this case, finely ground limestone was used as an internal additive, and a chemical reaction during the hydration process is not expected from it. The reason for its use is primarily to reduce the cement matrix porosity. The compensation of cement by finely ground limestone was 17%.

In total, it was designed eight concrete recipes with an assumed compressive strength of approximately 60 Mpa after 28 days. For all recipes, Portland cement CEM I 42,5 R, Mokrá was used. The amount of water and plasticising admixture was designed by a slump test for the S4 class, approximately 170 mm, to reach the consistency of fresh concrete. Thanks to identical consistency of all mixtures, it will be possible to monitor the influence of different aggregate types and granulometric curves, respective of the maximal aggregate grain, and also the impact of finely ground limestone on the resulting properties of the fresh and hardened concrete. For hardened concrete it will be monitored development of compressive strenght in age from 7 to 90 days. Another properties, which could predicate impermebility of the designed concrete are mainly the water absorption and the depth of penetration in age 7 till 90 days. Another monitored property that is closely associated with the water impermeability of concrete will be the assessment of the changes in concrete.

The measurement of volume changes will start from the fresh stage, right after mixing, up to 28 days. The composition of all recipes are stated in Table 1.

Table 1. Mix design

	O16	O22	Z16	Z22	O_L16	O_L22	Z_L16	Z_L22
CEM I 42, 5 R Mokrá [kg]	435	435	435	435	390	390	390	390
Limestone	-	-	-	-	80	80	80	80
DTK 0–4 mm Žabčice [%]	48.3	48.3	45.9	45.9	47.6	47.6	45.1	45.1
HTK 4–8 mm Žabčice [%]	-	-	13.3	-	-	-	13.6	-
HDK 4–8 mm Olbramovice [%]	11,3	-	-	-	11.7	-	-	-
HTK 8–16 mm Žabčice [%]	-	-	40.8	32.0	-	-	41.3	32.4
HDK 8–16 mm Olbramovice [%]	40.4	30.3	-	-	40.7	30.5	-	-
HTK 16–22 mm Žabčice [%]	-	-	-	22.1	-	-	-	-
HDK 11–22 mm Olbramovice [%]	-	21.4	-	-	-	21.9	-	22.5
MC Powerflow 2695 [kg]	3.5	3.5	3.5	3.5	3.9	3.9	3.9	3.9
Water [kg]	170	170	170	170	175	175	175	175

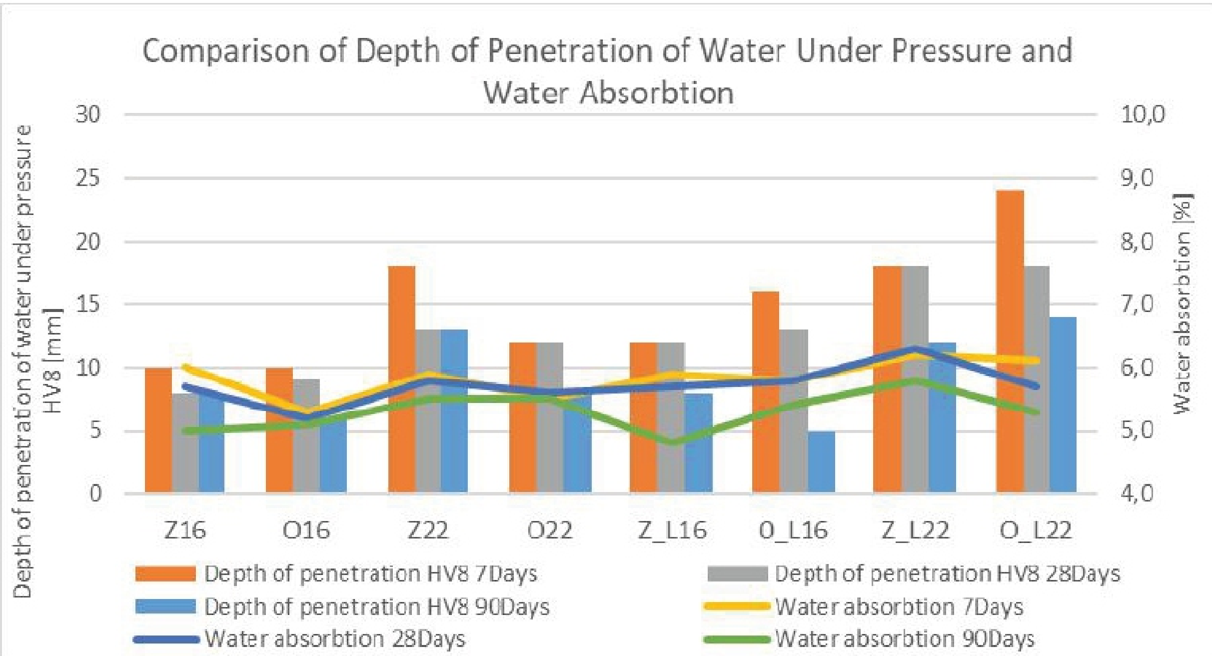

Figure 2. The determination of the depth of penetration of water under pressure and water absorption

3. RESULTS

3.1. The Determination of Compressive Strength, the Depth of Penetration, and the Water Absorption of Concrete

In the following part, the results of the monitored properties of designed recipes are summarised. Table 2 shows the results of compressive strength, water absorption, and the depth of penetration of water under pressure. Compressive strength was determined on cube-shaped bodies with an edge of 150mm at the age of 7, 28, 90. The determination of water absorption was performed following the ČSN 73 1316[13] standard on specimens in the shape of a 150-mm cube at 7, 28, and 90 days of age. The determination of the depth of penetration of water under pressure was performed on the water impermeability degree HV8 according to the methodology of TKP ŘVC ČR, where a specimen in the shape of a 150-mm cube is exposed to water pressure of 400 kPa for 24 hours and water pressure of 800 kPa for the next 48 hours. This methodology was chosen to meet the stricter criteria for constructions with high requirements for water impermeability of concrete, such as the construction of white boxes. This determination was also verified at the age of 7–90 days.

3.2. The Determination of Concrete Volume Changes

Another important property for ensuring the high resistance of concrete against the impact of water, primarily with regard to cracks and subsequent absorption of moisture and water into the construction, are volume changes in the concrete. Although the shrinking process is related to the chemical reaction of cement and water, an aggregate as an internal material plays an important role in resisting the disproportionate shrinkage of the cement paste. During the process of cement stone hydration, there is a process of tensile stress around grain of aggregate (in transit zone), and this tensile stress could lead to failure of concrete. [14,15] this is the reason why it is importantadhesive connection between aggregate and cement paste.

The impact of different aggregate types on concrete shrinkage is illustrated in Figure 3, and the exact shrinkage values are in μm/m and shown in Table 3.

Monitoring of the shrinking process was performed following the Austrian OENORM B 3329:2009-06-01 standard [16]. Shrinking troughs with a size of 60×100×1000 mm with a movable partition were used, and the connected sensor can monitor volume changes since the fresh concrete. The graphic progress of the shrinkage represents the arithmetic mean of three measurements.

Table 2. Summarised results of the depth of penetration of water, pressure, and water absorption

		O16	O22	Z16	Z22	O_L16	O_L22	Z_L16	Z_L22
Compressive strength [MPa]	7 days	57.3	60.4	52.0	56.4	60.0	57.8	52.6	52.8
	28 days	73.8	76.3	61.5	67.2	69.0	71.8	60.2	60.7
	90 days	76.2	79.3	63.2	68.1	77.5	78.8	63.7	68.0
The depth of water penetration HV8 [mm]	7 days	10	10	18	12	12	16	18	24
	28 days	8	9	13	12	12	13	18	18
	90 days	8	6	13	8	8	5	12	14
Water absorption [%]	7 days	6.0	5.3	5.9	5.5	5.9	5.8	6.2	6.1
	28 days	5.7	5.2	5.8	5.6	5.7	5.8	6.3	5.7
	90 days	5.0	5.1	5.5	5.5	4.8	5.4	5.8	5.3

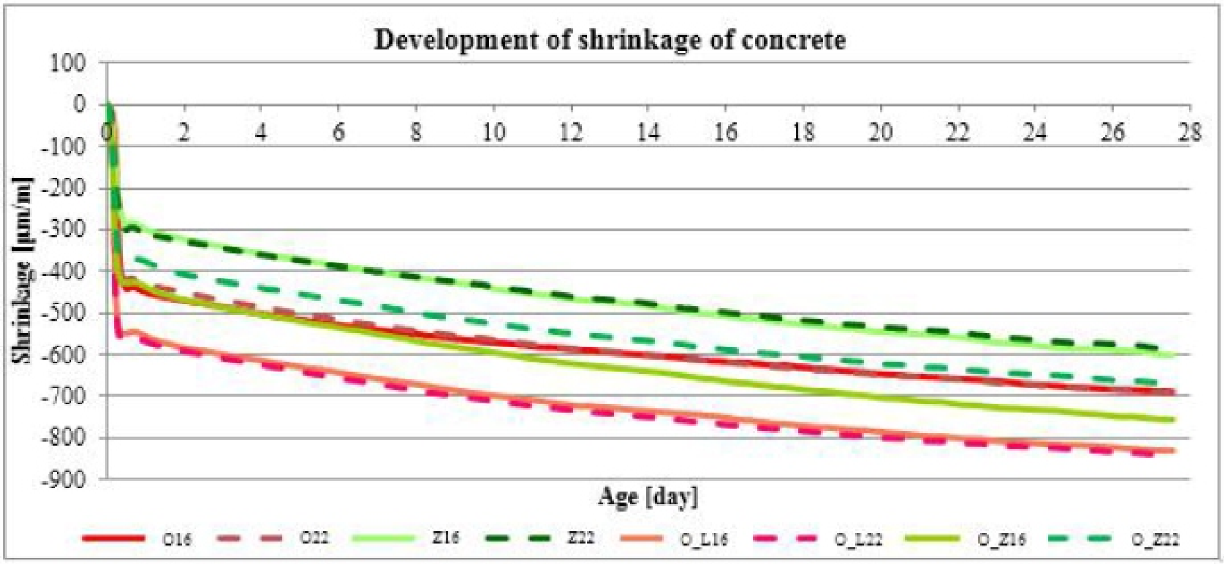

Figure 3. Graphic progress of volume changes

Table 3. Summarised results of volume changes

		O16	O22	Z16	Z22	O_L16	O_L22	Z_L16	Z_L22
Shrinkage [μm]	1st day	449	429	298	308	555	568	437	376
	7th day	540	530	401	402	658	671	551	484
	28th day	693	694	605	590	835	842	756	669

4. DISCUSSION

The determined compressive strength for all recipes shows significant dissimilarity between the types of aggregate. Within the designed recipes, a constant dose of binding agents was used for both types of concrete to monitor only the direct impact of the aggregate type, eventually limestone as an additive, on monitored parameters, primarily on volumetrics changes of concrete. Thanks to that, it was unequivocally proven that recipes with quality crushed aggregate reached noticeably higher compressive strength. However, the requirements of a minimum of 60 MPa after the 28-day-long standard load was reached for all recipes.

The results of the determination of the depth of penetration of water under pressure show higher levels of water impermeability for concretes using the crushed aggregate from Olbramovice, with which the lowest water absorption in depths of 5 mm and 6 mm was reached after 90 days. In general, the values of the depths of penetration decreased with the age of the samples for all recipes. When using the gravel from Žabčice, lower levels of water impermeability were achieved. According to the observed values, it can be said that the requirement of a maximal penetration of 60 mm stated in TKP ŘVC ČR is met for all cases. When comparing the continuous granulometric curve with the discontinuous granulometric curve, the values of the depth of penetration of water are almost identical. A similar trend is obvious in the results of the water absorption where the lower levels were reached with crushed aggregate, compared to the gravel.

However, these facts are most likely related to the properties of the aggregates. The psammite-type gravel of Žabčice shows higher water absorption than crushed granodiorite aggregate from Olbramovice.

The results of the experiment unequivocally prove that the dissimilarity of granulometric curves (continuous and discontinuous) and different Dmax does not have an impact on the water absorption of concrete.

The partial replacement of cement by finely ground limestone does not confirm the assumption of ensuring the lower porosity of a cement matrix and the results show higher water absorption, as well as deeper penetration of water under pressure. The results of the determination of volume changes point out the importance of the measurement of this process in the fresh mixture when the biggest portion (approximately 50%) of overall shrinkage occurred during the first day of concrete hardening. From the results of this experiment, we can unequivocally state that when using finely ground limestone, the level of shrinkage was higher in comparison with the mixture where no additive was used. Based on the acquired results, it is possible to say that the high fineness of limestone obviously leads to a bigger specific surface of the whole binding agent of the composite and during the reducing of the relative humidity of the sample, caused by the hardening, the mutual attraction of particles occurs, therefore, the volume changes are bigger.

The shrinkage values showed smaller volume changes when the Žabčice gravel was used. From the perspective of designing concrete mixtures with small volume changes, this knowledge seems very important. The result of the experiment is in partial conflict with the general theory in which crushed aggregate is considered as more suitable for production of these concrete types. General theories regarding concrete are based on the assumption that the bigger specific surface a crushed aggregate has will create a more positive impact on its incorporation into the cement matrix (the transit zone) and the aggregate will be more resistant to volume changes thanks to the unevenness of its grains. However, the result of the experiment proves that the water stuck on the surface of crushed aggregate grains most likely causes higher porosity of the transit zone, which leads to a higher shrinkage value of the whole composite. The surface of an almost regular round surface gravel catches little water, and so the transit zone is not affected by this water.

The impact of the maximal grain of the aggregate and discontinuous granulometric curve was not proven, and mixtures with identical types of aggregate show identical shrinking values at different curves. This result is positive especially for using the continuous granulometric curve, which is used more in practice thanks to its positive impact on some other mechanic parameters of concrete.

The results of the performed experiment also point out the improvement of the strength parameters at the continuous granulometric curve with Dmax 22 mm. This fact is connected to the statement that it is possible and appropriate to use higher Dmax.

5. CONCLUSIONS

This article deals with experimental research on the impact of different aggregate types and its composition on resulting concrete properties representing the water impermeability level of concrete for the construction of white boxes. Furthermore, this experiment verified the impact of finely ground limestone on the monitored parameters. During the design of the concrete mixtures, the use of a high amount of binding agent that is also used for ensuring the higher compactness of cement stone was considered. For all mixtures, identical consistency was ensured, so it was possible to evaluate the impact of different aggregate types, the maximum grain of the aggregate and finely ground limestone.

According to the obtained results, it was shown the unequivocal influence of various types of aggregate on the resulting compressive strength in all ages. When crushed aggregates were used, higher compressive strengths were achieved in all cases. From the results of the volume changes, the unequivocal impact of finely ground limestone is obvious when the negative impact on the resulting shrinkage was observed for all aggregate compositions. Moreover, the difference between gravel and crushed aggregate was observed, whereas significantly lower levels of shrinkage were achieved for gravel, both on the first day and day 28. The relation of volume changes and the depth of penetration of water and water absorption of different aggregate types was not clearly proven in this case. However, the resulting values of the performed experiments prove that it is possible to use both types of aggregates, and also continuous and discontinuous granulometric curves in the construction of white boxes. From the perspective of strength characteristics, the discontinuous granulometric curve with Dmax 22 mm and the use of crushed aggregates seems to be more suitable.

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High-Performance Concretes Intended for Deep Foundations of Constructions

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ABSTRACT

The term high-performance concrete (HPC) can be used to classify any concrete mixture that possesses some added value. One such category of concrete is concrete mixtures used in pile foundation, which must only allow a low degree of water separation (bleeding). The basic components of production of these concretes with high utility properties include the usability of active and passive admixtures and their mutual combinations. As part of this research, analysis of aspects affecting water separation from fresh concrete mixture, including dosing, and the type of individual raw materials, was performed. This article aims to utilise these results to analyse the impact of individual components and to provide a comprehensive theory for how to optimise the design of low-bleeding HPC based on the appropriate selection and mixing ratio of cement and admixture. A set of different raw materials and the effect of their mutual mixing ratios on bleeding and other mechanical and physical parameters of produced mixtures were verified. The results of this experiment demonstrate the clear relationship between the amount of binders up to size 0.25 mm and amount of water that separates under pressure. Very important aspect is morphology of grains used binders. These knowledge of realized experiment could be easily applied into the practise, same as designed methodology of usage combination of active and passive admixtures to create a maximum cement matrix compaction.

Keywords High-Performance Concrete, Deep Foundation, Bleeding, Packing

1.INTRODUCTION

Modern foundations of constructions, especially large industrial and engineering structures, are based on deep pile foundation technology. The principle of this method of building foundations is based upon the creation of supports abutting their ends to the bearable subsoil. Bored piles are most often used as supports. The length of such a pile depends directly on the depth of the bearable subsoil from the working joint, i.e. from the pile head, which further bears the load of other parts of the construction. This principle of deep foundation is shown in Figure 1.

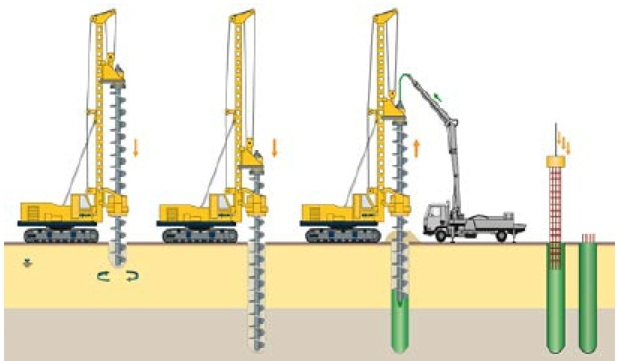

Figure 1. Scheme of production of bored deep piles

Concretes for pile production are divided into two categories according to the requirements of EN 206+A1. These are generally concretes intended for foundations used in dry and wet environments [1]. One of the greatest risks in terms of production and placement of concrete mixture during pile production is its segregation. Concrete used in pile production is generally required to have a high degree of consistency, which, in conjunction with the pressure caused by the weight of the concrete mixture in cases of long pile length, can cause segregation and increased separation of water from the concrete. This water separation is manifested by its ascension to the pile head surface and, in extreme cases, the whole concrete mixture stored in the pile can be degraded.

In terms of the durability of concretes used in pile foundations, there is often an increased demand for an XA environment, meaning an environment in which there is an occurrence of chemical substances. This chemical aggressiveness typically originates from groundwater.

However, there are certain exceptions such as when sulphate resistant cement is used. The design of concretes with increased resistance to aggressive environments must also respect the requirement for high resistance to water penetration into the internal structure of the composite. The described property can generally be referred to as the water-impermeability of concrete and testing of this aspect is based on standardised procedures.

All the properties of concrete described above, including a high degree of consistency, high resistance to water separation and a high degree of water tightness, can be positively influenced by the use of different types of active or passive admixtures. The correct use of admixtures in the production of high-performance concretes may be the only way to achieve these special properties that are required of the concrete mixtures.

1.1. Design of Concretes for Pile Foundation

The design of concretes intended for pile foundation must respect some special requirements resulting from the aggressiveness of the environment and the method of production of deep foundation and it must meet the requirements of the relevant standards. The basic concrete standard EN 206+A1 prescribes the minimum strength class and the minimum content of fine components in concrete for pile foundation. This standard also differentiates between dry and wet storage requirements. The requirements for the minimum content of fine components are based on the theory that a denser structure of cement composite is produced when higher doses of fine components are used.

According to the relevant standards, basic mechanical parameters such as compressive strength and other parameters directly related to the durability of the concrete composite must be verified in pile foundation concretes. These properties include water absorption and depth of pressure water leakage. In terms of fresh concrete mixture, in addition to the consistency that most often achieves the degree of cone slump S3 to S4 according to EN 12350-2 [2], these properties enable the determination of levels of water separation. There are a number of guidance documents for the determination of this parameter of a fresh concrete mixture, which often produce different results. No standardised procedure for this test has been issued in the Czech Republic. The most frequently used procedure is based on the Austrian directive ÖBV - Merkblatt 'Weiche Betone' [3]. The test procedure detailed by this directive is based on the determination of the amount of water pushed out from the fresh concrete mixture at the specified pressure.

Inappropriate designs of concrete intended for pile foundation that do not respect the requirement for a high degree of resistance to water bleeding and segregation can lead to irresolvable failures, which can have a negative impact, not only on the durability of the resulting pile, but also on its static load bearing capacity.

According to the standard provided by EN 206+A1, passive and active admixtures can be used for concretes for pile foundation. The use of these admixtures has several positive effects in terms of economic savings, but also, more crucially, in terms of increasing the ratio of fine components used in the concrete mixture, which has a positive effect on the stability of the mixture.

1.1.1. Pile Failures and the Use of Admixtures

The most frequent failures of pile foundations caused by issues with concrete mixtures are increased bleeding and segregation. If the concrete mixture shows an increased tendency to bleed, it may cause significant failures in a pile foundation. A large dose of fresh concrete mixture set in a relatively narrow profile (diameter) with a large height is used for the production of a deep pile. As a result, high pressure stresses arising from the gravity load of the mixture itself are developed and this pressure stress has a major effect on the movement of water towards the top of the pile. The subsequent deterioration of the upper part of a pile caused by excessive bleeding can be seen in Figure 2 [4].

Figure 2. The upper part of the pile damaged by excessive bleeding

In extreme cases, a strong aggregate segregation of the concrete mixture may occur as a result of the movement of cement milk to the upper part of the pile. These failures have a significant impact on the durability of the concrete composite and, in extreme cases, lead to the loss of the pile's static function.

According to the results of several pieces of research and general theories, the resistance of a concrete mixture to bleeding can be positively influenced by the use of an increased dose of fine particles, usually measuring between 0.125mm and 0.250mm. Given this increased dose can only be achieved with certain amounts of cement, this method would be very uneconomical and environmentally unsuitable. It is, therefore, generally recommended to use the content of fine aggregate particles or admixtures in the production of such concrete. Suitable types of admixtures include those with a higher specific surface. In general, both active and passive admixtures can be used.

The general purpose of the use of active or passive admixtures is to increase the dose of fine components in the concrete mixture in order to have a positive effect on the resistance to bleeding. In terms of durability, its use is a prerequisite for creating a dense microstructure with high resistance to penetration of aggressive media. With regards to the formation of neoplasms similar to cement hydration products, active admixtures can help to create the maximum density microstructure. However, some studies have considered the suitability of optimal dosing of admixtures in terms of the density of binder mixtures in a dry state. This approach, which can generally be referred to as 'packing', can be used effectively when combining different types of admixtures. Their mutually optimal combination, in terms of the maximum density of a mixture in a dry state, can significantly contribute to the density of the whole concrete matrix [5], [6]. The concept of packing can be seen in Figure. 3.

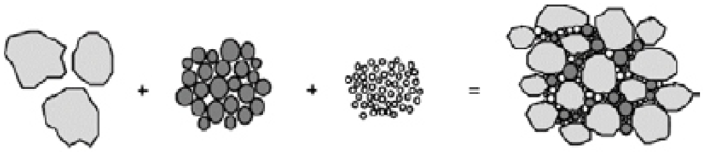

Figure 3. The concept of 'packing'

2. METHODS AND RESULTS

Six concrete mixtures were designed during our experiment. These mixtures differed from each other in the type of admixture used and one sample containing no admixture was used for reference purposes. The design of the concrete mixtures was based on the standards for concrete intended for pile foundations in wet environments.

For all mixtures except the reference mixture, the same grading curve of the aggregate mixture was used, consisting of DTK 0-4mm, HTK 4-8mm, HDK 8-16mm and HDK 11-22mm. The reference mixture consisted of the same aggregate fractions, but their distribution was different from the distributions of those used in the higher dose 0-4mm fraction that substituted the missing fine particles when using admixtures.

The admixture dosing was measured based on the aim of maintaining the same compressive strength after 28 days of normal curing. In tests where combinations of two admixtures were used, their combination was determined using software that calculates the optimum mixing ratio based on the grading curves of the individual components. An example of the resulting graph showing the dependence of the individual types of admixtures mixing on the density of this mixture in a dry state is shown in Figure 4. This optimal mixing ratio ensures that the maximum density of the resulting mixture of mixed components in a dry state is achieved, which is an example of packing.

All the concrete mixtures were produced with the S4 consistency using the slump cone method according to EN 12350-2.

The specific composition of all the concrete mixtures is shown in the following Table 1.

Table 1. The composition of designed concrete mixtures

	REF	L7	L9	FA	FA+L7	FA+L9
CEM I 42,5 R	375	315	315	300	300	300
Limestone No. 7	-	120	-	-	50	-
Limestone No. 9	-	-	120	-	-	67
Fly ash	-	-	-	120	70	53
DTK 0-4mm	825	745	735	740	745	745
HTK 4-8mm	235	235	235	235	235	235
HDK 8-16mm	475	475	470	475	475	475
HDK 11-22mm	360	360	355	360	360	360
Water	165	175	175	173	170	175
Superplasticizer. additive	3.0	4.2	4.3	3.3	4.0	4.4

Prior to the production of concrete mixtures, their specific surface was determined for all used binder components using an automatic Blaine apparatus. It was hypothesised that this parameter could directly relate to the bleeding value of the produced concrete mixtures. The results are shown in Table 2.

The concrete mixtures produced were subjected to a slump cone test, in accordance with EN 12350-2 [2], five minutes after production and a test to determine water separation of the concrete under pressure based on the Austrian directive ÖBV - Merkblatt 'Weiche Betone' [3]. The bleeding was determined using a 10 cm3 steel vessel under a pressure of 3 bar. The captured water, which was pushed from the concrete mixture by pressure, was measured after 15 and 60 minutes. The test apparatus is shown in Figure 5. This test simulates the pressure generated by the concrete mixture in the pile's own weight after its production.

Table 2. Specific weight and specific surface of the binder components used according to Blaine

	Specific weight [g/cm^3]	Specific surface [cm^2/g]
CEM I 42,5 R	3.09	4200
Limestone No. 7	2.77	3120
Limestone No. 9	2.75	4490
Fly ash	2.25	2900
L 7. + FA	2.43	2980
L 9. + FA	2.50	3650

The photographs show an obvious loss of concrete volume after 60 minutes at a pressure of 3 bar. The resulting values of water separation, together with the consistency of the concrete mixtures and the concrete density of the mixtures in a fresh state according to EN 12350-6 [7] are shown in Table 3.

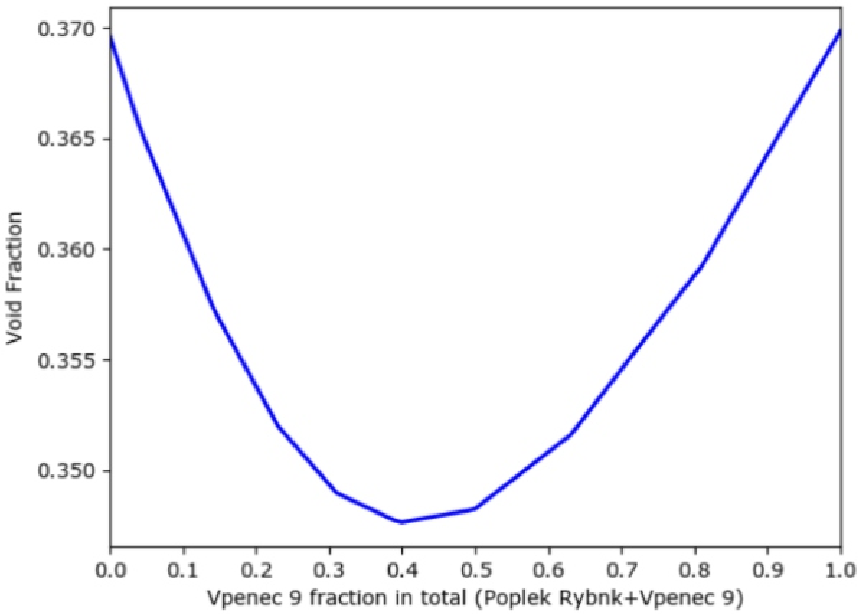

Figure 4. Curve of optimal mixing ratio in terms of density

Figure 5. Equipment for determining water separation from concrete according to ÖBV during and after the test

Table 3. Water separation values of concrete and properties in the fresh state

	REF	L7	L9	FA	FA+L7	FA+L9
Water separation after 15 min [ml]	320	220	188	300	305	300
Water separation after 90 min [ml]	505	375	382	463	475	470
Slump after 5 min [mm]	190	190	190	180	180	180
Fresh concrete density [kg/m^3]	2390	2370	2370	2360	2380	2390

Table 4. Results of monitored properties of concrete in hardened state

	REF	L7	L9	FA	FA+L7	FA+L9
Cured concrete density - after 7 days [kg/m3]	2400	2390	2380	2350	2360	2380
Cured concrete density - after 28 days [kg/m3]	2390	2390	2380	2360	2380	2400
Cured concrete density - after 90 days [kg/m3]	2390	2390	2390	2360	2390	2390
Compressive strength - after 7 days [MPa]	45.2	41.8	40.5	41.0	41.2	45.2
Compressive strength - after 28 days [MPa]	51.1	53.4	51.9	53.3	55.2	58.0
Compressive strength - after 90 days [MPa]	51.6	57.7	53.1	68.0	64.6	64.8
Watertightness HV8 - after 7 days [mm]	26	19	20	22	21	25
Watertightness HV8 - after 28 days [mm]	21	15	16	21	16	21
Watertightness HV8 - after 90 days [mm]	20	10	11	8	13	15
Water absorption - after 7 days [%]	6.2	5.6	6.0	6.1	6.1	5.9
Water absorption - after 28 days [%]	5.8	5.6	5.8	6.0	5.9	5.6
Water absorption - after 90 days [%]	5.8	5.5	5.8	5.6	5.6	6.0

Cube-shaped bodies with a 150mm edge were made using the concrete mixtures and these bodies were stored in an aqueous environment at a temperature of 20°C throughout the curing period. The compressive strength, according to EN 12390-3 [8]; density of hardened concrete, according to EN 12390-7 [9]; watertightness of hardened concrete, in accordance with TKP ŘVC 1 [10], and water absorption, according to ČSN 73 1316 [11], were determined on the manufactured bodies after 7, 28 and 90 days. The method for determining the watertightness was chosen in light of the requirement for a higher water pressure to be used in the test than is used for the harmonised standard EN 12390-8 [12]. The test water pressure was 800 kPa. All test results are shown in Table 4.

Figure 6 shows the dependence of the number of fine components up to 0.250mm on the bleeding of individual formulas. Also included in this number of fine components are fine components up to the same size originating from aggregates. In order to ensure the thoroughness of the analysis of the impact of the specific surface of the whole system of binder components, such as cement including admixtures, the specific surface, according to Blaine, was determined for this system as well. These results are shown in Table 5. Graphical dependence, as highlighted by Figure 7, shows the impact of the specific surface of the entire binder mixture on the concrete separation.

Table 5. Specific surface of the binder system according to Blaine

Formula designation	Specific surface [cm^2/g]
REF	4200
L7	3840
L9	4270
POP	3830
POP + L7	3820
POP + L9	4030

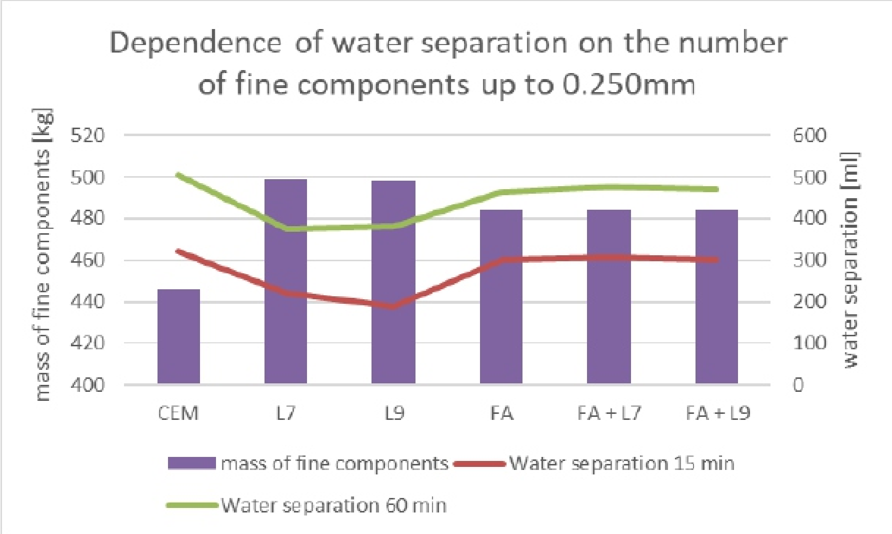

Figure 6. Dependence of water separation on the number of fine components up to 0.250mm

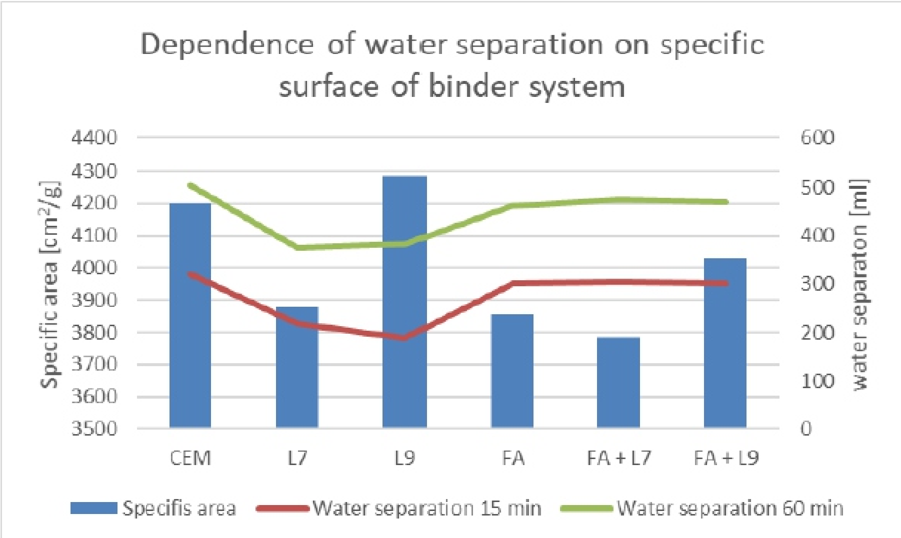

Figure 7. Dependence of water separation on specific surface of binder system

The graphical dependencies and results show considerable differences in water separation of the limestones and fly ash used, although the specific surface of the whole binder mixture does not differ significantly. For this reason, high temperature fly ash and limestone grains were monitored under a scanning electron microscope (SEM). Their morphology was monitored in terms of shape, which could be directly related to water separation itself. Figures 8 and 9 are photos of fly ash and No. 9 limestone grains.

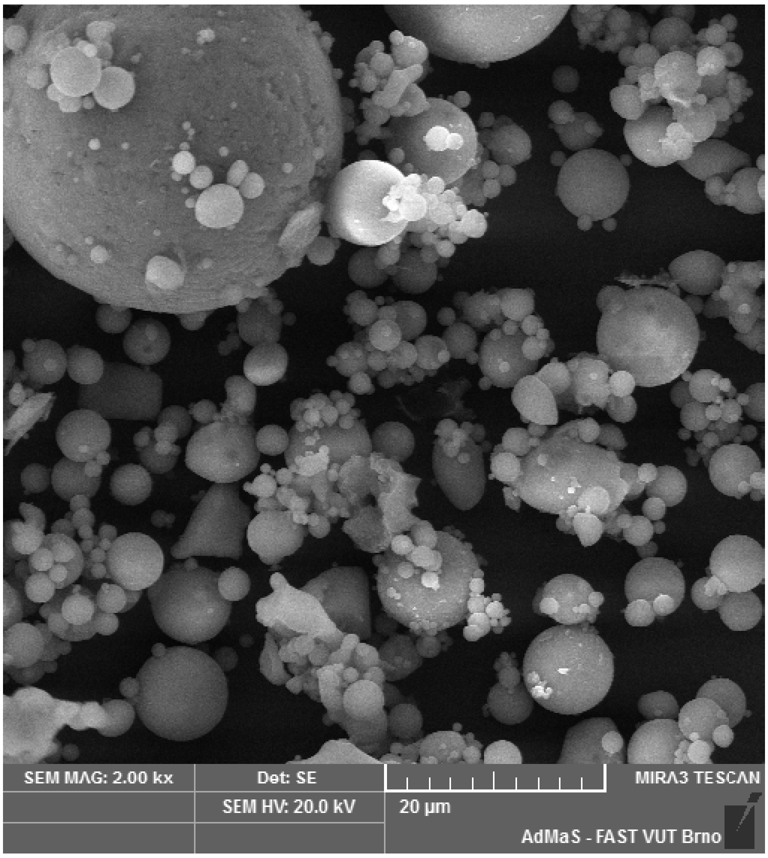

Figure 8. Fly ash grains under SEM - 2000 times magnification

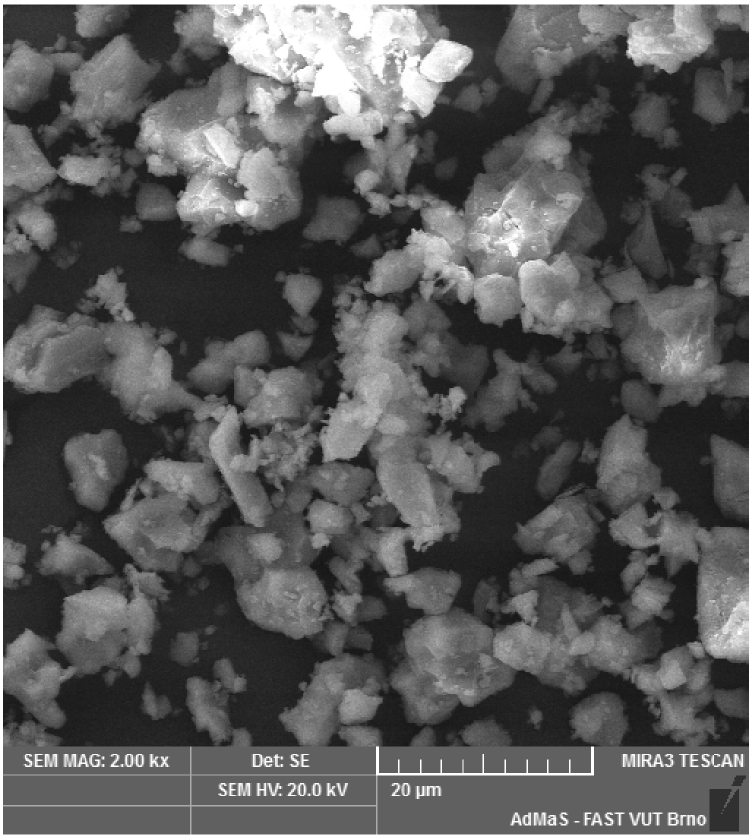

Figure 9. Limestone No. 9 grains under SEM - 2000 times magnification

3. DISCUSSION

The results of the experiment demonstrate the suitability of using admixtures for the production of concrete intended for pile foundations of constructions. In terms of water separation, we can see a direct correlation between the number of fine components in concrete up to the size of 0.250mm and the amount of separated water under pressure. With regards to the dependence of water separation on the specific surface of a whole binder system, it is not possible to draw clear conclusions. Of all the admixtures used, high-temperature fly ash appears to be the least suitable. Although the mixtures in which high-temperature fly ash was used show only a slightly lower value for the specific surface of the whole binder system than the formulas using limestone, the water separation of these mixtures is noticeably higher. This probably relates to the grain morphology of the high-temperature fly ash itself, which was monitored under SEM. As expected, the morphology of the grains of high-temperature fly ash and the limestone used was very different. The fly ash grains are predominantly spherical in nature with a glassy surface, which corresponds with widely accepted knowledge of high-temperature fly ash. As a result, it can be assumed that water adhered to a grain surface separates under pressure. From the results of the experiment, very finely grounded No. 9 limestone or recipes made using it seem to be the most suitable materials. This admixture shows the highest value of the specific surface and the grain morphology provides a very heterogeneous impression with the possibility of water absorption on its surface.

However, high-temperature fly ash is an active pozzolanic admixture, which is commonly used to improve the rheological behaviour of a concrete mixture and the quality of cement stone in the long term due to the formation of CSH gels. This experiment demonstrated that this pozzolanic property can be seen as a factor in the highest increase in compressive strength between 7 and 90 days and a decrease in the watertightness value of HV8. High-temperature fly ash is generally one of the most widely used admixtures for the production of these types of concrete for pile foundation.

In terms of strength parameters and watertightness of concrete, the use of the packing concept seems to be suitable. In this experiment, the benefits of using the optimal combination of active admixture, in the form of high-temperature fly ash mixed with a passive admixture in the form of limestone filler, were monitored.

Mixtures with optimised admixture dosing have not been shown to have a positive impact on water separation. Water separation occurred at the same levels as when only using high-temperature fly ash. However, the benefit of this method of dosing the admixtures is that it helps achieve better mechanical parameters, in particular, in this experiment, in terms of achieving a higher compressive strength. Mixtures with optimised dosing of admixtures exhibit the highest compressive strength values after 28 days and these strengths exceed those determined for each admixture individually.

Within the development of concretes intended for pile foundations of constructions, it can be said that the most significant factor in the water separation value of the concrete mixture is the type of admixture used. Admixtures showing high specific surface and suitable grain morphology seem to be most suitable. However, it is necessary to find a suitable boundary between the specific surface value of the binder components and the necessary dose of water to achieve the desired degree of consistency. In terms of the possible impact on the durability of concrete mixtures, the concept of packing of dosing admixtures appears to be highly beneficial. The use of a denser microstructure of cement matrix results in better mechanical parameters of the concrete and the density of the microstructure is expected to have a direct impact on the penetration resistance of aggressive media [13].

4. CONCLUSIONS

The results of this experiment demonstrate the suitability of using admixtures for the production of concretes intended for pile foundations of constructions. In terms of water separation, there is a clear relationship between the specific surface of a binder system and the amount of water that separates under pressure. However, the most important parameters affecting separation of water from concrete include the morphology of the admixtures used.

It is necessary to pay particular attention to the production of high-quality concretes intended for pile foundations of constructions, particularly in terms of possible bleeding and segregation. Both of these undesirable properties of a fresh concrete mix can cause a significant deterioration in the durability of the concrete pile or a loss of its static function.

The use of admixtures of active or passive types seems to be highly beneficial to the production of these types of concretes. The relationship between the water separation value and the specific surface of an admixture and its grain morphology was monitored. Passive admixtures, in the form of very finely grounded limestone, were recognised in this experiment to be the most suitable. By using the optimum dosage of admixtures according to the packing rule, a higher compressive strength was achieved after 28 days of standard curing compared with the compressive strength of concrete mixtures using individual types of admixture. With regards to the water separation value from concrete, it was not possible to prove the positive effect of using admixtures.

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Application of Sustainable Road Drainage System: Simulation by Using SWMM Program

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ABSTRACT

High levels of rainfall are generally followed by increased volume of surface runoff and the potential for standing water. Stagnant water on the roads has a negative impact on road users and road damage. The concept of sustainable road drainage has the potential to be developed in dealing with the quantity of runoff water. This study aims to evaluate the existing road drainage system and implement a sustainable road drainage system. The location chosen as the object of research is Diponegoro University Campus area, Tembalang District, Semarang City. Use of the SWMM program which contains a set of flexible hydraulic modeling capabilities used to direct runoff and external inflows through a network of pipe drainage systems, channels, storage units and diversion structures.From the results of the hydrograph analysis, the largest discharge was found in the Outfall of the Center for Environmental Research with a discharge of 5.7 m3 / sec and the lowest discharge at the outfall of the Faculty of Business Economics with a discharge of 0.07 m3 / sec. Whereas the longest flood time that occurred was at the Outfall of the Faculty of Business Economics with a time of 4 hours 45 minutes and the shortest flooding time was at the Jurang Belimbing Outfall with 1 hour and 15 minutes. The sustainable road drainage system model applied is a road drainage channel with the addition of fine and coarse aggregate filters to the channel and integrated with infiltration wells. Thus, the drainage channel is able to reduce surface water flow to other areas and improve water quality.

Keywords Sustainable Roads Drainage, Simulation, SWMM

1. INTRODUCTION

In quantity, rainfall that falls on the surface of the roads and its surroundings will burden the drainage system. Stagnant water that occurs during the rainy season in Indonesia can become a flood if not anticipated and managed properly. This incident occurs in almost all cities in Indonesia and recurs every year, but this problem has not been resolved, it even tends to increase, both frequency, breadth, depth and duration. Therefore every development of the city must be followed by an evaluation and improvement of the overall drainage system, not only at the development site, but also the surrounding area affected (Rudiono, 2018). Serious problems, especially in the rainy season where there is a pool of water, so that it can have a negative impact on the surrounding community and the condition of the road itself such as damage to roads and interrupted traffic flow (Hendratta, 2014). Drainage facilities are provided to ensure timely runoff of surface water generated from large impermeable surfaces. Good drainage is also supported by surface slopes that have adequate slope (Owuama, 2014).

Surface water runoff in cities has a negative impact on receiver flow and various solutions have been proposed to limit the effects of urbanization on water balance. This solution suggests managing urban runoff and reducing sources of pollutants (Rizzo et al., 2018).

Our observations on the campus environment of Diponegoro University revealed that the existing drainage system still uses the concept of conventional drainage, which is made of waterproof channels, causing disruption to the hydrological cycle. Surface water flow increases, groundwater replenishment decreases and the level of water quality also decreases. Surface water runoff increases, groundwater replenishment decreases and water quality levels also decrease. Water is very important for urban development, although urban flooding greatly affects city life. Urban spatial planning sets new patterns for natural drainage systems and changes the hydrological cycle, increasing peak discharge. The urban drainage system is designed to deal with sanitation problems and suffice the system for higher runoff. Traditional flood control projects tend to focus on increasing disposal capacity. The concept of sustainability in urban drainage, states that urban flooding is not only transferred, but is absorbed into the ground (infiltration) and the drainage system must be planned together with urban development (Miguez, Bahiense, Rezende, & Veról, 2012). Therefore it is necessary to develop an environmentally friendly road drainage system, which is a drainage system that is able to control surface runoff and maintain runoff water quality conditions. Sustainable Urban Drainage Systems (SUDS) is a system consisting of one or more structures that are built to manage surface runoff. Sustainable drainage systems have gained increasing public interest in recent years, as a result of their positive effects on water quality and quantity problems and additional recreational facilities felt in the urban landscape (Zhou, 2014).

The sustainable drainage system aims to reduce problems caused by surface runoff, it also aims to reduce the problem of water pollution (aquatic) and increase the value of water use, especially in urban environments.

Drainage ecology to support sustainable drainage systems in urban areas, especially in developing countries (Parkinson & Mark, 2005). The use of infiltration practices as a basis for developing sustainable urban drainage systems is limited to excessive pollution in runoff water, especially from roads, due to land availability. (Mrowiec, 2016). Sustainable drainage systems (SuDS) have become a promising solution to improve watertight by reducing the volume of water flow and flow rates, and improving water quality (Kanso et al., 2018).

The concept of an environmentally friendly or sustainable road drainage system where surface water runoff is infiltrated through an integrated artificial facility consisting of side channels, filter layers and infiltration wells (Yunianta, Suripin, & Setiadji, 2018). So a sustainable urban drainage system (SUDS) was developed to model a drainage system that absorbs runoff water to the ground or is often referred to as infiltration. This infiltration system forwards runoff water into drainage channels and is processed with filters to filter out pollutants or wastes involved in runoff water. Filtration systems use geotextiles or other media as pollutants or waste filters (Golio, 2001). Drain / Infiltration Trenches Filter Drains / Infiltration Trench uses a drainage system on the right and left side of the road as a permeable media that can drain runoff water on the road and carry out temporary water treatment before the water is drained to the ground. The results showed that the concept of sustainable road drainage has the potential to be developed in handling the quantity of runoff water. The relationship between rainfall, runoff volume, area ratio, dimensions of drainage channels, aggregate filters on the channel and integrated into infiltration wells, was developed to realize a sustainable road drainage model (Yunianta, Suripin, & Setiadji, 2019). The total efficiency of runoff reduction in infiltration trenches can be used as a main indicator of rainfall performance management.

Analytic equations were derived to estimate the rate of runoff reduction in infiltration trenches. Equations taken as input variables are the area coverage, storage space provided by the trench reservoir, the rate of ground water infiltration through the bottom of the soil trench, and parameters representing local climatic conditions (Guo & Guo, 2018).

Low-impact development (LID) enables greater development potential with less environmental impact using flood water control distributed at locations that achieve a good balance between conservation, growth, ecosystem protection, and public safety (J. C. Y. Guo, 2009). The growth of cities must be carefully planned, to deal with relevant hydrological changes, which are caused by the effects of urbanization. Often, the increase in surface areas that are waterproof is a major cause of urban flooding. For this reason, the concept of a new urban drainage design has been investigated in recent decades, seeking a more sustainable storm water management approach. The concept of sustainability in urban drainage implies that flooding may not be transferred downstream.

Storage and infiltration measures, distributed in watersheds and integrated with urban landscapes, must be introduced to reduce flood peaks and rearrange flood flow patterns (Miguez, Bahiense, Rezende, & Veról, 2014).

SWMM software program provides convenience in determining flood discharge and determining the location of drainage disposal outlets in an area, and will make it easier to design drainage channels. SWMM is part of a continuous effort study to model the anticipated performance of flood management practices and models that can calculate the percentage reduction in runoff volume, reduction of peak runoff discharge, runoff hydrograph time, and potential runoff reduction due to infiltration. (Abi Aad, Suidan, & Shuster, 2010). SWMM provides environmental integration for study area data input, hydrology, water quality simulation, and hydraulics.

Besides that it is also a flexible hydraulic model that is used to direct runoff water and inflow through a network of drainage pipes, channels, storage units, and diversion structures (Rossman, 2010). Studies that apply the SWMM model to flood management adjacent to a road.

Runoff water basin infiltration are instrumented at both inlet and outlet locations. This model is used to simulate flood performance in hydrographs and pollutants during different flood events (Wang, Forman, & Davis, 2018).

SWMM is used to design a drainage system that efficiently handles flooding with a 10-year payback period design with the provision of a multi-use containment pool. This multipurpose containment pool helps reduce the peak flow of hydrograph that comes out downstream and also functions as a rain structure. Observations were made on a large number of drainage problems that could be resolved by providing proper connectivity in the runoff water channel and keeping it clean during the rainy season (Bisht et al., 2016).

Road drainage canals in the Dipoengoro University Campus in Semarang, Tembalang District, Semarang City, still use channels with open channel types that are on the right and left of the road. The drainage system still drains surface water to be moved to other lower places or other receiving water bodies such as rivers. This condition is still moving water from one location to another so that it burdens the quantity of water in another place which can certainly create problems in other areas. For this reason, a drainage system is needed that is more environmentally friendly and can improve water use in the campus area. Typical conditions of roads and drainage channels in the Dipoengoro University Campus in Semarang are shown in Figure 1.

Figure 1. Typical Existing Condition of the Jalan Drainage Canal in the Tembalang Undip Area

The purpose of this study is to evaluate the existing drainage system, especially drainage that is on the side of the road or road drainage in the campus environment Undip Tembalang, to get an outfall or outlet point and flood discharge that occurs in the drainage system with the SWMM program. Application of sustainable road drainage models, in order to improve water quality with infiltration systems and the use of infiltration wells as reservoirs. The system is to increase the carrying capacity of the environment, land conservation and restore the water cycle. It is worth to note that the use of the term road in this study refers to the regulations that apply in Indonesia. The road according to Indonesian Law No. 38 of 2004 article 1 paragraph (4) is defined as land transportation infrastructure which covers all parts of the road, including complementary buildings and equipment intended for traffic that is on the surface of land and / or water, and above the water surface, except railroad tracks, lorry road, and cable road. In this study the road in question is a road that is in an urban area with flexible pavement or rigid pavement with equipment, including the existence of a road drainage system.

2. METHOD

In general, hydrological analysis is a preliminary analysis part in the design of hydraulic buildings. The understanding contained therein is that the information and quantities obtained in hydrological analysis are important input in subsequent analyzes. Hydrologic phenomena such as the amount of rainfall, temperature, evaporation, sun exposure time, wind speed, river discharge, river water level, flow velocity and river sediment concentration will always change with time. In general, hydrological analysis is a preliminary analysis part in the design of hydraulic buildings. Hydraulic buildings in the field of civil engineering can be in the form of culverts, weirs, overflow buildings, flood retaining embankments, and so on. The location chosen as the object of research is Semarang City especially Diponegoro University Campus Area, Tembalang District. Hydrological analysis is needed to calculate flood discharge at Tembalang UNDIP Campus. The steps to get the discharge plan are as follows:

1. Distribution of Regional Rainfall (Area CA)

To get an idea of the distribution of rain throughout the CA, several stations were chosen that were scattered throughout the CA. Selected stations are stations that are within the watershed area coverage and have complete rain measurement data. Some methods that can be used to determine average rainfall are the Thiessen, Arithmetic and Isohyet Maps. In this hydrological analysis, it uses a rain station reference, Sta Rain Pucanggading.

2. Analysis of Rainfall UNDIP Tembalang Campus Area

Rain calculation for this study location is in the form of annual daily rainfall with a data length of 25 years, from 1994 to 2018. The number of rain stations used is 1 (one) rain station close to CA, namely the Pucanggading rainfall station. From this data, the rainfall data at the Pucanggading Rain Station represents the characteristics of rain in the study area.

3. Rainfall Intensity Analysis

Analysis of rainfall intensity can be processed from rainfall data that has occurred in the past. Analysis of rainfall intensity related to concentration time (tc).

The formula used to find the concentration time uses the Kirpich equation, as follows:

$$t_c = \left(\frac{0{,}87xL^2}{1000xS}\right)^{0{,}385}$$

where:

t_c : concentration time (hours)
L : length of waterway from the farthest point to the point being observed (km)
S : average slope of the water course

Table 1. Results of Calculation of Concentration Time (tc)

Basin	Length		Elevation		Slope	tc	tc (Rounded)
	m	km	Upstream	Downstream		(Hour)	
UNDIP Campus	651.47	0.65	211.50	198.00	0.0207	0.025	1.00

Source: Results of Analysis, 2019

The planned rainfall data is used as a basis for calculating the magnitude of rainfall intensity. This is done by approaching an hourly rain hyetograph diagram. Next is the Hyetograph of Rainy Days CA Campus UNDIP Tembalang.

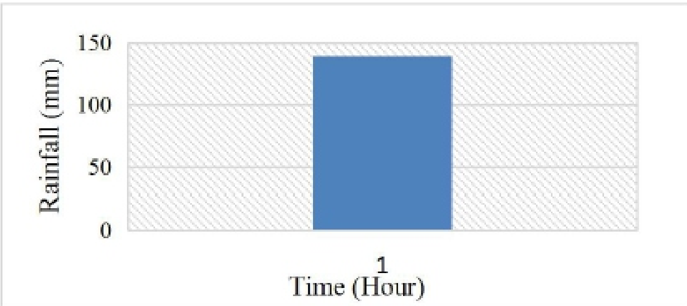


Figure 2. Rainy Hour Hyetograph of CA Tembalang UNDIP Campus

The percentage in the hydrograph is multiplied by the rainfall plan to get the amount of rainfall intensity. The following calculation of rainfall intensity for the return period of 5 years.

Table 2. Results of Rain Intensity Calculation

Rainfall Plan (5 th)	Rainfall The Hour (%)	Rainfall Intensity (mm)
139	100 %	139

In the design of the road drainage model the formula is used to determine the dimensions of the drainage channel based on the aggregate requirements for the filter, assuming using permeable pavement. Permeable pavement technology is an important aspect in sustainable design. One tool in the design of sustainable infrastructure is the use of permeable pavement systems to help reduce flood water runoff. The ability to use large areas occupied by pavement to improve hydrology and groundwater replenishment has many benefits (Hein, Swan, & Schaus, 2010).

Permeable sidewalks are one of the most important Low Impact Development (LID) techniques. Usually used to reduce runoff volume, peak flow and pollutant load. Despite the lack of adequate modeling tools is a limiting factor in permeable pavement diffusion. Modeling infiltration phenomena in porous media is very complex because of its highly unsaturated character (Carbone, Brunetti, & Piro, 2014).

In determining the dimensions of the applied road drainage channel, the calculation of aggregate filter depth is assumed by following the permeable pavement calculation procedure with Equation below (Smith, 2006).

$$d_p = \frac{\Delta Q_c R + P - fT}{V_r}$$

where:

d_p = Aggregate depth (m)

ΔQ_c = total runoff from coverage area contribution (m / hr)

R = (A_c/A_p) the value of the contribution of the coverage area with permeable area

P = rainfall design (m)

f = infiltration rate design (m/hr)

T = effective time of infiltration (hr)

Vr = void ratio for aggregate

4. RESULTS

The Catchment Area reviewed in the calculation is Tembalang UNDIP Campus which is then divided into Subcatchments. The depiction of subcatchment is done by dividing residential areas and roads that are adapted to drainage channels in existing conditions. In addition, the depiction of subcatchment is also determined based on the flow direction and elevation in the existing conditions. Water system and retention ponds Subcatchment in the SWMM model can be seen in Figure 3.

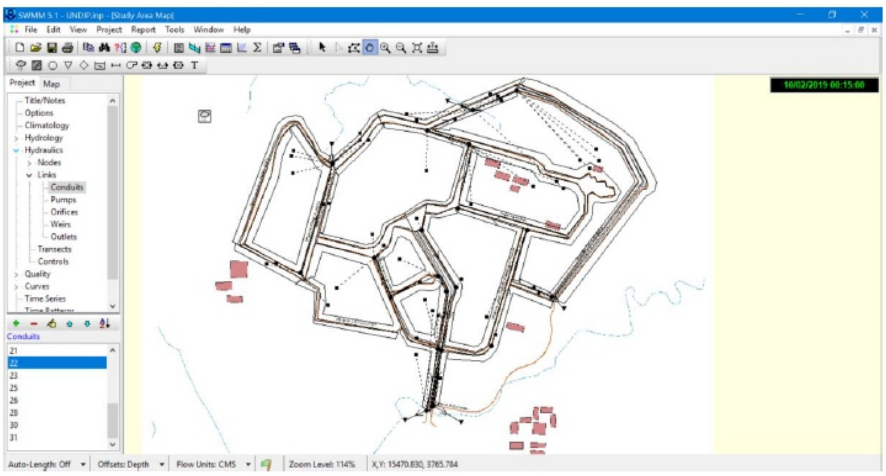
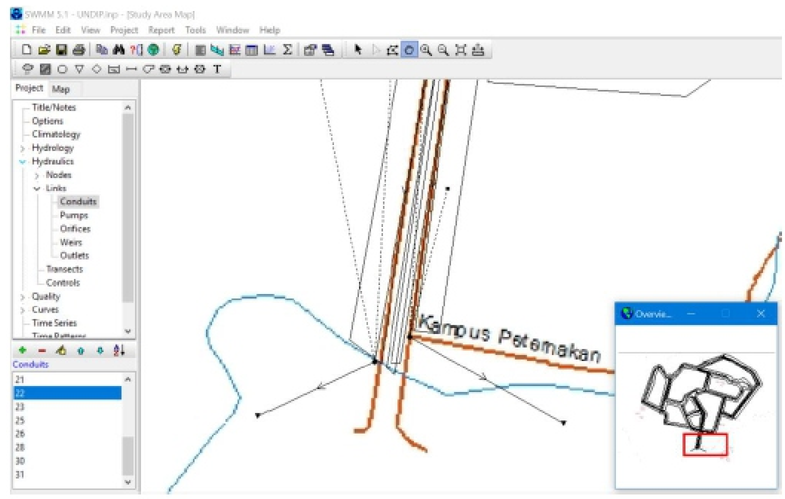
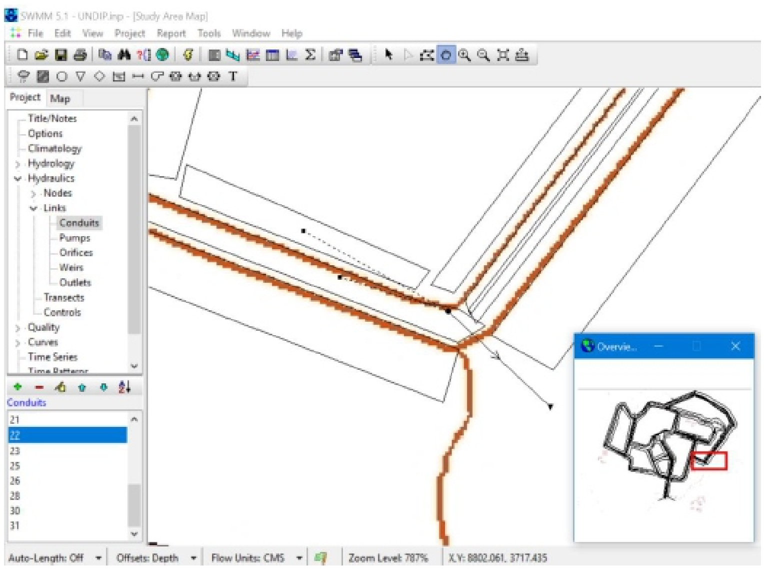


Figure 3. Subcatchment Network in the SWMM Model

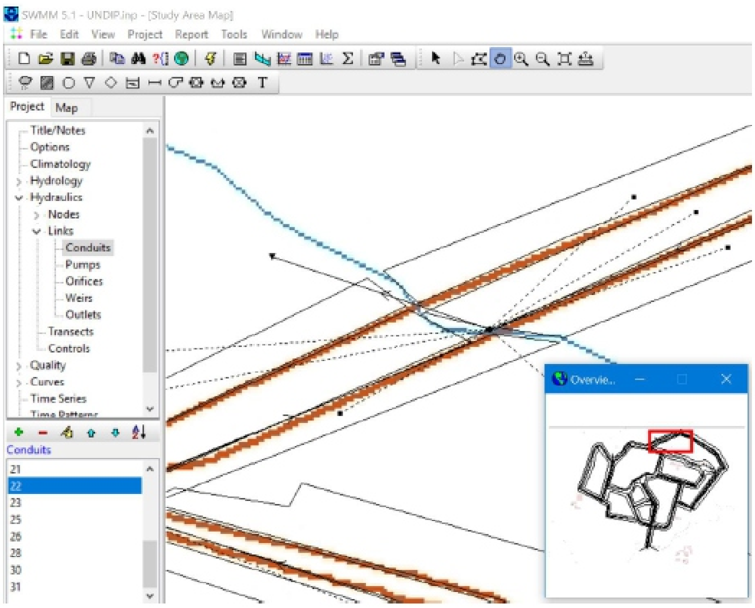
Actual conditions in the field indicate that there are several outfalls or discharges on the Tembalang UNDIP Campus as shown in Figure 4.



1. Outfall at the campus entrance close to the Faculty of Animal Husbandry (Animal Husbandry Outfall)



2.Outfall next to the Jurang Belimbing village



3. Outfall next to the Faculty of Economics and Business (FEB Outfall)

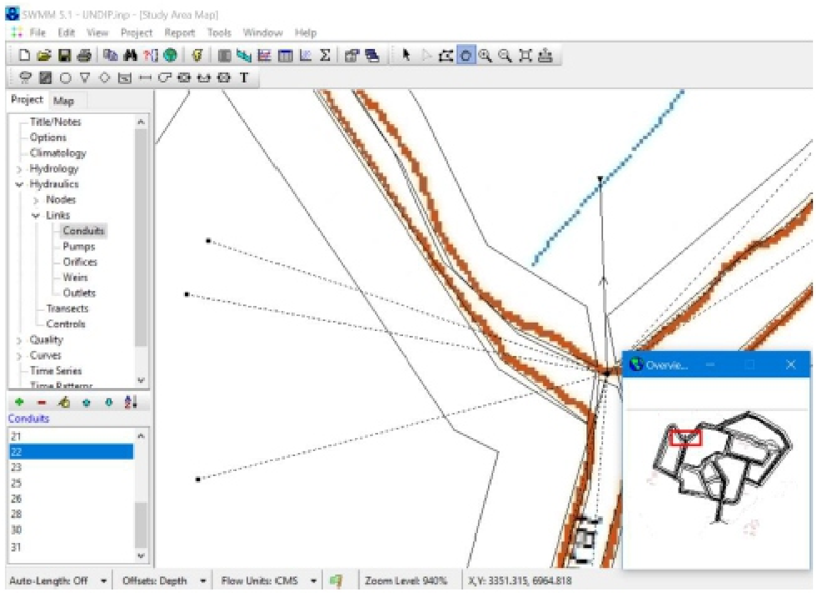
	4. Outfall near PPLH Office (PPLH Outfall)

Figure 4. Outfall Points in Tembalang Undip Campus Area

Based on the results of running rainfall-runoff using the SWMM model, the results of the flood hydrograph at each outfall are shown in figures 5 to 9.

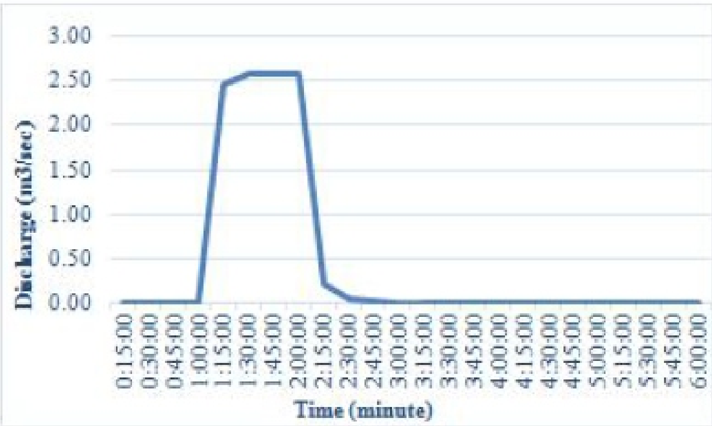


Figure 5. The Left Side Faculty of Animal Husbandry Flood Hydrograph

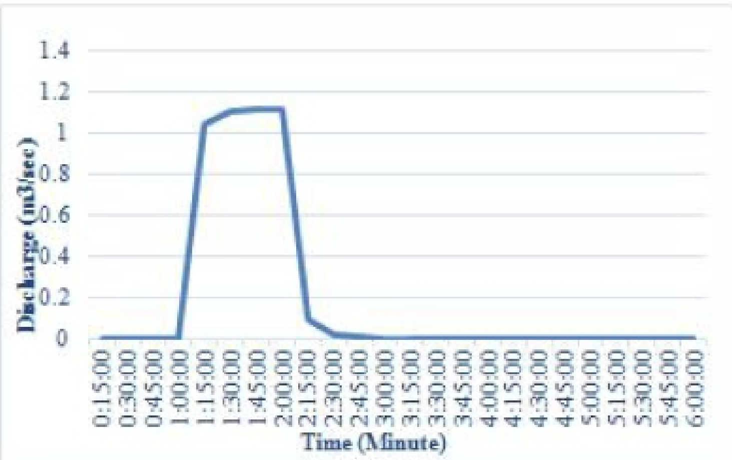


Figure 6. Right Side of the Faculty of Animal Husbandry Flood Hydrograph

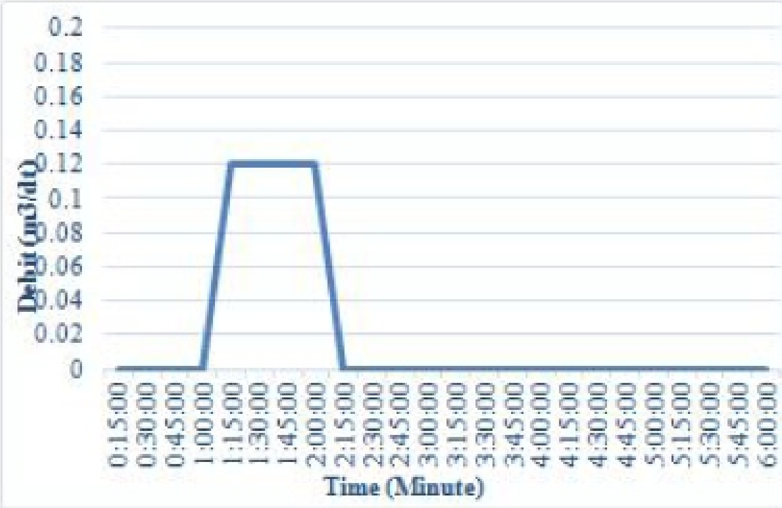


Figure 7. Jurang Belimbing Flood Hydrograph

Figure 8. FEB Outfall Flood Hydrograph

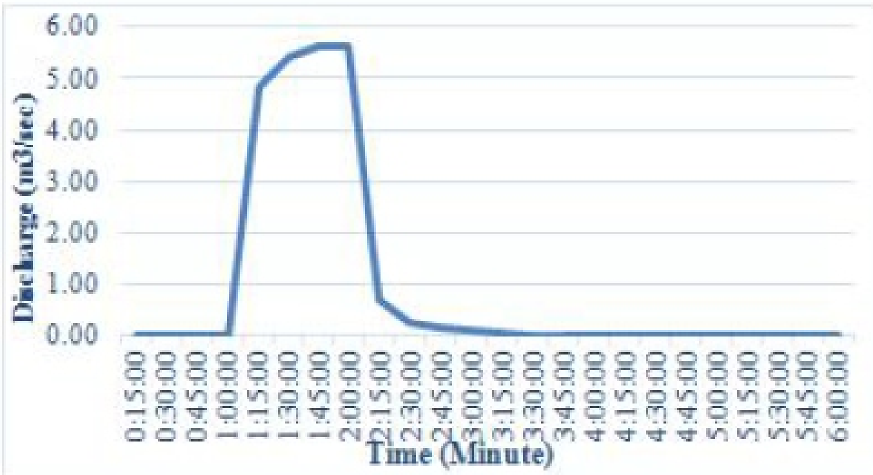


Figure 9. PPLH Outfall Flood Hydrograph

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Calculation of the aggregate depth required for the aggregate filter is:

$$d_p = \frac{\left(\frac{1.44}{77.5}\right) x \left(\frac{77.5}{0.7x5}\right) + 0.1219168 - 0.00675}{0.4} = 1.3\ m$$

So with a width of the upper 70 cm channel a 130 cm channel depth will be obtained, for more details calculating the detailed relationship between the width and aggregate depth is presented in Table 3. and Figure 10.

Table 3. Aggregate Width and Depth Count

Wide (m)	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
Depth (m)	7.3	3.8	2.6	2.0	1.7	1.5	1.3	1.2	1.1	1.0

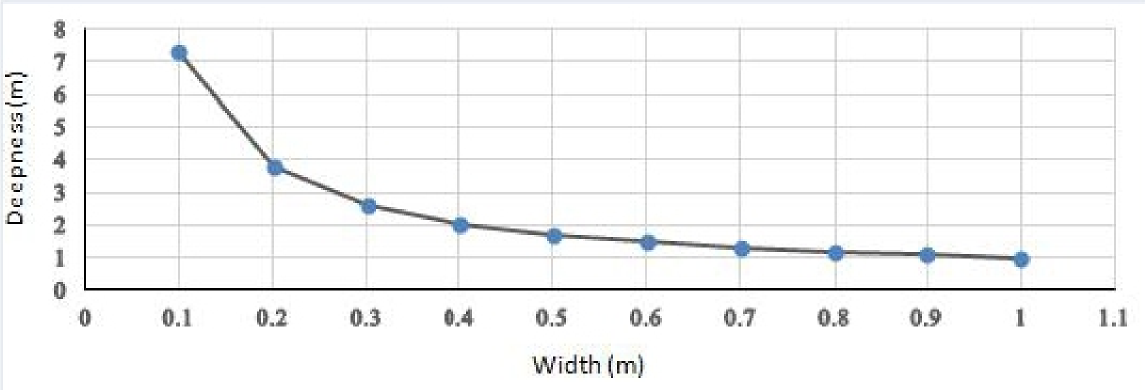

Figure 10. Graph of Aggregate Width and Depth Relationship.

From these results, it was applied to the road drainage channel as in the design of the drainage model with the design of the drainage channel model made of pre-cast concrete quadrilateral (U-ditch) with modifications to the bottom of the channel made water reservoirs. In the drainage channel, fine aggregates and coarse aggregates are placed as filters, and seams are placed between the aggregates. The side of the water reservoir is connected by a pipe to the infiltration well as the final water infiltration into the ground. With this road drainage model, surface water can be absorbed into the ground and not flowed elsewhere. The existence of aggregate filters will also improve the quality of water entering the ground. Details of the road drainage model are shown in Figure 11 and Figure 12.

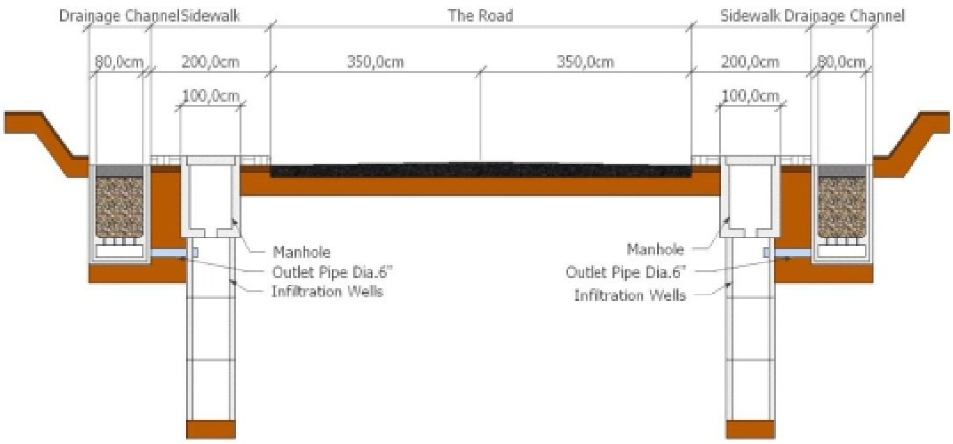

Figure 11. Typical Cross section of the Road

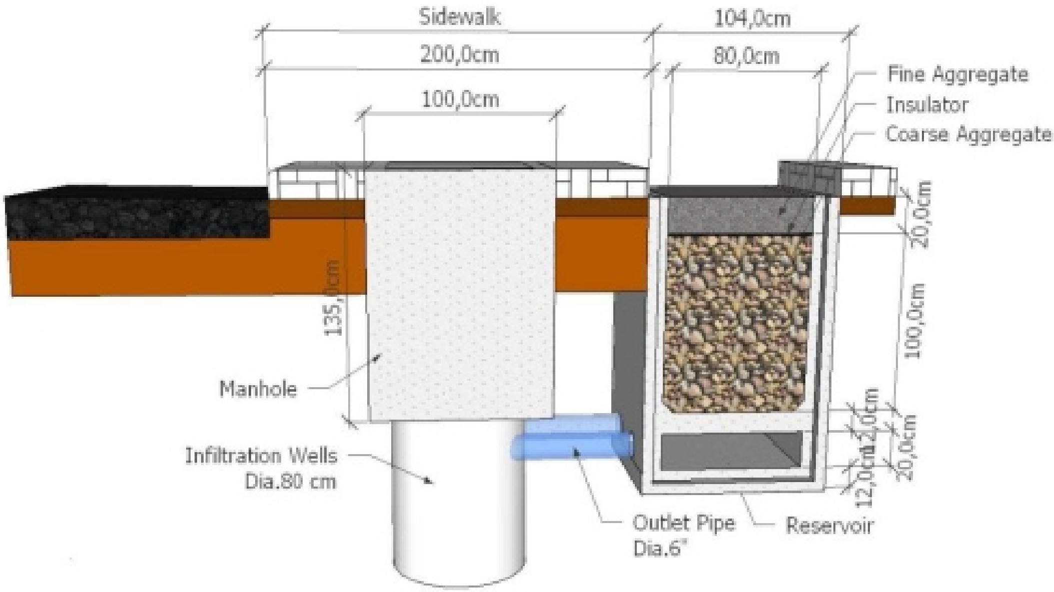

Figure 12. Typical Details of Infiltration Channels and Wells Models

4. CONCLUSION

The area analyzed includes all drainage on existing roads in the Diponegoro Tembalang University campus area. From the simulation results there are four outfall drainage roads namely; outfall Left Side Animal Husbandry Campus with a debit of 2.51 m3 / second and time of 1 hour 30 minutes, Outfall Right Side Animal Husbandry with a discharge of 1,1 m3/ second and time of 1 hour 30 minutes, Outfall of the Jurang Belimbing with a debit of 0,12 m3/ second and time of 1 hour 15 minutes, Outfall of the Gap in the Faculty of Business Economics with a debit of 0,007 m3/ sec and a time of 4 hours 45 minutes and an Outfall of the Environmental Research Center with a discharge of 5,7 m3/ second a time of 2 hours. From the results of the hydrograph analysis, the largest discharge was found in the Outfall of the Center for Environmental Research with a discharge of 5.7 m3 / sec and the lowest discharge in the outfall of the Faculty of Economics and Business (FEB) with a debit of 0.007 m3 / sec. The longest flood time that occurred was at the Outfall of the Faculty of Economics and Business (FEB) with a time of 4 hours 45 minutes and the shortest flooding time was at the Jurang Belimbing Outfall with 1 hour and 15 minut The results of the aggregate depth calculation are used to assume the depth of the drainage channel that is the total depth of the channel 169 cm and width 104 cm. And the overall aggregate depth is 120 cm with fine aggregate details of 20 cm and coarse aggregate of 100 cm and inter-aggregate sealing is used. It is hoped that with the concept of a sustainable road drainage model, this will be able to overcome runoff and can absorb water into the soil that is around the roads, so that water does not run off to other areas. Moreover, the existence of an aggregate filter in the channel can improve the quality of water that seeps into the soil.

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Aesthetics of Modern Architecture: A Semiological Survey on the Aesthetic Contribution of Modern Architecture

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ABSTRACT

Starting from the Industrial Revolution, continuous technical progress in Modern Architecture introduced new dimensions to the traditional methods of construction. Thus, Modern Architecture had a tremendous effect in introducing new approaches to the aesthetic understanding of the built environment. In addition, there are a lot of criticism on the philosophy of Modern Architecture and the idea of Machine Age Architecture led to the lack of sense of place and cultural detachment. This study aimed to assess the existing gap in literature by using a qualitative assessment of literature on Modern Architecture and stylistic classification of architectural movements in the Modern era. Overall, the study concludes that ignoring cultural values and its semiological references in architectural design are the most important aesthetic factor that led to the failure of Modern Architecture.

Keywords Modern Architecture, Aesthetic Contribution, Semiological Survey, Stylistic Classification

1. INTRODUCTION

The birth of Modern Architecture was perceived to begin with the 19th century along with the industrial revolution and the concomitant introduction of mass production which stirred a general detestation of historicism, interest in functionalist planning, the use of modern building materials and existing new technologies (Ali, 2018; Arenibafo, 2018). Considering this fact, Modern Architecture is characterized by simple rectilinear shapes, plain undecorated walls, bald facades and often times, dull colors using simple elementary shapes, lines, and forms as basis for design. Modern Architecture is celebrated for architectural milestone because it provided the template that easily detached from the historical umbilical cord and permanently changing the traditional and future course of architectural discuss. All of these brought along with it, radical urban changes (owing to the new technologies), which further affected radical aesthetic changes and a new concept of the construction (Amiri, 2016).

Apart from positive contributions of Modern architecture, it can be seen that there are many criticisms on Modern Architecture. The first of these was Robert Venturi in his book: "Complexity and Contradiction in Architecture" revealed that the modern architecture of the 1960s according to Nesbitt (1996) "had been reduced to formulaic repetition of canonical works of the Modern Movement, to technological utopias, and to expressionist fantasies". Robert Venturi's maxim that "less is bore" was a bold declaration premised of a pluralistic and multi-dimensional approach that redirected from the reductivist school of the Modern Movement.

According to Tadao Ando, Modern Architecture is an attempt to solve real life problems by numbers and measurable standards (Ando, 1993:7) and as a result, the "make-up" and mythical aspects of architecture are ignored. Hence, Ando considers that most often than none, the products of Modern Architecture have no stories to tell, but are simply purely functional and without messages that stirs our fascination. It just exists without provoking the audience (Ando, 2002). Against this backdrop, Norberg-Schulz argued that from ab-initio, Modern Architecture was not meant to have a regional character but sought to be an "international" language (Norberg-Schulz, 1988:135). This led to the problem of "loss of place", loss of the character of places and overall loss of place identity. Considering the above-which somehow reveals the non-aesthetic quality of Modern Architecture, this study by qualitative assessment of literature on the philosophy of Modern Architecture, aimed to examine the main indicators shaping the aesthetic quality of modern architecture and to classify them into specific aesthetic characteristics. These specific characteristics are highlighted as architectural styles of Modern Architecture.

2.MATERIALS AND METHODS

2.1. Modern Architecture as a Style

As earlier stated, Modernist Architecture (or simply stated- Modernism) emerged in the early-20th century as answer to enormous changes in both society and technology. It was associated with functionalist rationalism, the abhorrence of ornaments, analytical viewpoints and a rational use of materials. It took roots in Europe and in particular, the German school of Architecture- the Bauhaus. The Bauhaus made important contributions, such as "less is more" (Frampton, 1992) in the evolution Modern Architecture. The school was however brought under strong Nazi persecution and as a result, immigrated to the United States. Consequent upon which Modern Architecture also travelled along with it. In the United States, the influence of Modern Architecture became more legible and it was renamed "the International Style". The International Style projected similar characteristics to the Modern Movement such as beige and clinical white colored buildings, weightlessness, disdain of ornamentation and the rejection of tradition (Salvo, 2015; Jaff et all, 2017).

Modern Architecture simply defined is the abstraction of basic forms, shapes and lines to create clean and simple undecorated rectilinear forms. Needless saying that its aesthetic language is conveyed by fundamentally simple geometric forms such as rectangles and squares. The maxims: 'form follows function', 'fitness for purpose' are all inextricably interwoven with Modern Architecture. Thus, Modern Architecture is primarily concerned with the functionality of spaces and its form derives from this. Several architects have their own maxims defining their philosophy of architecture. The following table illustrates the famous maxims (and their period in time) peculiar to certain famous architects.

As can be seen, the most noticeable buildings of Modern Architecture which are mentioned in Table 1 are the results of developments in technologies and have developed its own specific aesthetic characteristics. This study, by qualitative analysis of the philosophy of Modern Architecture and critical analysis of existing literature, illustrates the main aesthetic characteristics of the Modern Architecture.

Main protagonist often associated with the development of High Modernism were Walter Gropius, Le Corbusier and Ludwig Mies van der Rohe and Adolf Loos.

2.1.1. Walter Gropius and the Beginning of Modern Architecture

In Germany, Modernism is akin to the Bauhaus. The Bauhaus was founded by Walter Gropius in 1919. It sought to integrate scholarship (pure arts) with crafts and this brought new insights to art training (Aziz Amen, 2017). Gropius was a visionary and his aim was to harmonize technology and arts consequent upon which he trained a new generation of designers and architects to reject historicism and accept the new dogma – the Modern Movement. In the overall, Gropius largely re-discovered the tenets of Modern

Architecture which developed into the international style (Frampton and Futagawa, 1983). The suspended glass wall provided a clear case in point. Instead of being set back from the supporting columns of the building, it was suspended outside the columns enabling a lucid display its non-structural function.

2.1.2. Le Corbusier's and the Notion of Machine Aesthetics

Le Corbusier's popular maxim, 'the house is a machine for living' showed that machine aesthetic is an important concept for functionality, standardization and rationalism that altogether underpinned the idea of Modern Architecture (Le Corbusier, 1986). This maxim meant that a house is conceptually analogous to a machine and as such, should be built the same way a machine (such as a car) was fabricated. This led to the notion of standardization, implying the production of standardized prototypes for construction. Edward Jeanerette (as Le Corbusier was also called) further extended this idea to city scale (Evenson, 1969). The idea also led to the introduction of logic, scholarship and systemic reasoning as the basis for architectural designs and further provided ways that systematize the relationship between man and the living space. 'The key modern principle for Le Corbusier was function, and this is where the machine metaphor is so important' (Le Corbusier, 1986). To state it succinctly in summing-up, Le Corbusier's emphasis if anything was that standardization is the key to Architecture fulfilling its functions.

2.1.3 Mies van der Rohe

A major actor in the realization of the International style was Mies van der Rohe. Along with Walter Gropius and Le Corbusier in the early 1920s, he reinforced the notion of the International Style as the core movement of Modern Architecture. Mies advocated the Minimalist Architecture through the minimal use of space, curtain wall, columns and beams and sparing use of industrial materials. He metaphorically denoted that the rigid columns and beams are bones while the cladding is the skin; thus his well-known maxim: "skin-and-bones". Mies's encouraged maximum flexibility of spatial layout, which according to him represents maximum spatial utility. His steel-and-glass aesthetic became a template for Modern Architecture for decades even after his death. Meanwhile, his designs have always expressed practical aesthetic- a beauty that serves its inhabitants.

Table 1. Famous maxims in Modern Architecture that affected the development of modern aesthetics

Theoretician	Motto	Name Of The Building Designed based on this Theory	Architect	Date Of Construction
Adolf Loos 1870-1933	"Ornamentations is Crime."	Steiner House	Adolf Loos	1910
Louis Sullivan 1856-1924	"Form Follows Function."	Bauhaus school	Walter Gropius	1926
Le Corbusier 1887-1965	"A house is a machine for living in."	Villa Savoye	Le Corbusier	1929-1931
Mies van der Rohe 1886-1969	"Less is more."	Glass House	Philip Johnson	1949
	"God is in the details."	Seagram Building	Mies van der Rohe	1958
Frank Lloyd Wright 1867-1959	"An idea is salvation by imagination"	Falling Water	Frank Lloyd Wright	1936-1939

Table 2. Aesthetic characteristics, implementing ideas and philosophy of Modern Architecture

Implementing Ideas	Philosophy	Architectural Characteristic
-Standardization of Architecture. -Rational order.	-Machine age Aesthetics. -Scientific and logical reasoning. -Architectural system for human well-being.	-Structural Possibilities. -Open plan design. - Large windows and open floor plans. -Simple shapes.
- Standardization	-Need for Mass housing.	-Five points of architecture. -Pre-Fabrication
-Simplified Forms -Functional forms -Based on Kant's theory of form.	-Abstraction -Clean Aesthetic	-Box-like building. -Cubic volume, a flat roof. -Clean lines.
-Functionality and Open Floor Plan.	-Functional design -Transparency	-Uses and Benefits of Glass - Dom-Ino House
-Rejection of traditional styles.	-Ornamentation is crime.	-Simple forms with no ornamentations.
- Rectangular Forms. -Horizontal and Vertical Lines.	-Juxtapose against the horizontal elements.	-Materials in good distinct planes. - Materials give a intense effect.
-Low, Horizontal Massing.	-Horizontal Planes	-Flat Roofs
-Concrete	-Highlighting the honesty of Materials. -Stained and exposed materials.	-Open column free spaces. -Domino Houses
-Maximize the entry of light into a building. - CIAM approaches .	-Increasing the quality of life. -The necessity of using natural light in design. -Promote human comfort and health.	-Large glass windows from ceiling to floor. -Façade steel frame construction. -Five points of architecture. -Fully glazed exterior walls.

2.1.4. Adolf Loos and the Notion of Crime for Ornamentation

Adolf Loos, in 1908 published his seminal essay "Ornament and Crime" where he justified this assertion and advanced that architecture should renounce ornamentation. Loos argued that ornamentations in buildings served the purpose of selfish and childish entertainment. He observed that owing to mass production, in certain countries, ornament no longer serves its cultural function, and should therefore not be seen as an expression of culture.

2.2. Chronological and Stylistic Classification of Modern Architecture

2.2.1. Early Modern Architecture

From aesthetic point of view, Modern Architecture would be classified to two main eras which are: a) Early Modern Architecture and b) High modern Architecture. Moreover, Modern Architecture in its nascent stage, which was about the 19th century, was a number of buildings with similar characteristics. Primarily this was the simplification of form and the total abhorrence of the ornament. By the 1940s these characteristics had consolidated as the International Style. This study classifies the aesthetic tendencies in early Modern Architecture into the following three categories:

a. Technical Rationalism or Rationalist tendencies:

b. Architectural Formalism or Formalism tendencies:

c. Functional tendencies:

2.2.1.1. The Technical Rationalism

Rationalism is the notion that the structure determines the form. It is the philosophy that the material of construction bespeaks architectural expression. The school accepts and promotes the employment of science theory, technology and techniques in Architecture (Nia and Rahbarianyazd, 2019) while it rejects excessive décor. Rational architects used the philosophy of Rene Descartes -the father of modern philosophy (1596-1650) - and highlighted ideal proportions and geometric forms. The architecture of Étienne-Louis Boullée (1728–99) and Claude Nicholas Ledoux (1736–1806) characterize the Enlightenment rationalism, with their pure approaches to design such as including spheres, squares, geometric forms, and cylinders (Ianca, & Georgescu, 2018).

2.2.1.2. The Formalism

Referencing his "Theory of Forms" and in particular his synthesis of Eidos[1], it can be recalled that formalism started with Plato, and with Immanuel Kant's definition of the "aesthetic judgment" and his formulation regarding the sovereignty of the aesthetic object and self-sufficiency. Kant's epistemology has impacted German Formalism, and roundabout, Russian Formalism (Ianca, S & Georgescu, 2018). Within the framework of this Formalism, the shape of the building became germane to modern aesthetic. Foremost amongst the Formalist styles in Early Modern era and their aesthetic language are shown in the table below:

Table 3. Aesthetic characteristics of the foremost styles of Formalism tendencies in early modern era

	Aims/ Ideas	Aesthetic Characteristics
Arts and Crafts Movement 1860-1910	-Reaction to undesirable aesthetic concerns of the Industrial Revolution. - Preserve individual craftsmanship, Decorative arts	-Built of natural materials. -Historicizing elements such as steep roofs, prominent chimneys, cross gables, and exposed-beam ceilings.
Beaux Arts Architecture 1885 - 1945	-Classicism, Classical Revival -Eclectic form of Neoclassicism. - Imposing scale and Classical principles.	-Characterized by formal design, order, symmetry, grandiosity - Elaborate ornamentation. -Triangular pediments.
Art Nouveau 1890-1910	- Rejects academic traditions and historicism. - Spread over artistic designs to everyday objects. -Supported the use of exterior decoration.	-Flowing curves based on natural forms, Asymmetric. -Classic ornamentations - Mosaics Stained glass and Japanese motifs.
Gothic Revival Neo-Gothic 1905-1930	-Powerful sense of height. - Scholarly approach to the revival of past styles. -Create an experience of the inspiring. - Sense of transcendent greatness.	-Strong vertical lines. -Ribbed vaulting. -Use of steep gables.
Expressionism 1905-1925	-Protest against the academic architecture. -Function follow form. -Express feelings of the viewer, inner sensitivities. -Included abstraction.	-Alteration of form for an emotional effect. -The reduction of realism to symbolic. -Stylistic expression of inner experience.
Futurism 1909-1945	-Highlighted the aesthetics of speed, technology and change. - The elements of entirely new mechanical world. - Anti-historicism.	-long dynamic lines, suggesting speed, motion, urgency and lyricism. -Rejected the traditional aesthetics. -Glorify life based machine and motion.
Constructivism 1914 - 1932	- Aesthetic and decorative function of structure. -Instill the avant-garde in everyday life. - Universal harmony - Unification of art and life	-Materials of steel and glass and its futuristic philosophy. -Sense of presence and scale. -Application of 3D cubism to non-objective and abstract elements. -Neoplastic aesthetic.
De Stijl 1917- 1931	-Supporting primary colors and the purity of geometrical shape. - The idea of a universal language. - Expressed utopian ideal of spiritual order. -Using pure geometric form to achieve pure abstraction.	-Being based on the principles of "cubism". -Consists of the three primary colors (yellow, red and blue). - The three primary values (white, black and gray). - Vertical and horizontal lines, asymmetry, geometric forms. -Long rectangular windows, and free-floating outer walls, flat roofs.

[1] *Plato uses Eidos in some methodically different ways, sometimes meaning extension of a Form and sometimes meaning Form.*

Art Deco 1925-1945	- Reaction to the sensuousness and flowing lines of the previous of Art Nouveau and Beaux-Arts styles.	-Zig-zags, strong lines, repeating geometric patterns and symbolism. -Symmetry, simple composition, rectilinear rather than curvilinear shapes, and lavish ornamentation. -Stucco, concrete block, glazed brick, smooth-faced stone.
Art Moderne Machine Age Architecture 1935-1950	- Represents the last phase of Art Deco - Became the prevalent style of commercial, public, and domestic architecture. - Machine aesthetic focused on mass production.	-Glass blocks for windows and aluminum or stainless steel. - Asymmetrical facades, flat Roof and horizontal emphasis. -Minimal decoration and Speed and movement. - Corner windows, Rounded edges, Curved canopies.

2.2.1.3. Functionalism

Striving for balance between buildings aesthetic and functionality came to forefront with Viollet-le-Duc in the in the second half of 20th century. This was followed up by L. Sullivan, whose aphorism "the form follows the function" became peculiar with principles of functionalism in the early Modern era. Functionalism brings to mind the selflessness of the space (mostly in office and industrial buildings) in which case, a space dedicated to a particular function can be reversed and used otherwise. In other words, the space becomes multi-functional. Its main aesthetic features are typically a reflection of the novel technologies available for construction and execution and the availability of new construction materials which include glass, concrete, plastics, aluminum and steel for the purpose. In modern period, due to the essence of the era, three main "schools" of functionalist architecture which are the "Bauhaus School" and "Chicago School" and Prier school have been highlighted.

2.2.1.3.1. Bauhaus, School

Bauhaus, a school of Arts and Craft, was pioneered by Walter Gropius in Germany. The school, which was founded in 1919, believed in the unity of Arts, attempted to harmonize crafts with pure arts and stood for a synthesis of the arts, ranging from the furniture details to the level of urban organization (Periton, 2011; Saletnik & Schuldenfrei, 2009; Siebenbrodt, 2009). Bauhaus forerun standardization by initiating prefabricated elements for building, and thereby redefined the aesthetics of industrial product and mass production. Influenced by the art philosophy, the school favors buildings innately endowed with sculptural presence; howbeit in addition, it sets function before the form. Modern buildings designed in the Bauhaus are light structured, constructed in glass, steel and concrete with stained glass facades.

2.2.1.3.2. Chicago's School

Following the Chicago Fire of 1871, which left most of the urban core area ruined, the need for extensive rebuilding while at the same time adopting a much higher fire safety precaution became imperative. This is especially important because at that point in time, the population of Chicago was rapidly tending to a million. The rising costs of real estate and the introduction of elevators in Chicago following the urban renewal had also encouraged vertical building construction which impacted emphasis on vertical aesthetic since then.

2.2.1.3.3. Prairie School

The protagonists of the Prairie School were John Ruskin, William Morris amongst others. The school emerged as the result of growing sympathy with the design aesthetics and ideals of the Arts and Crafts Movement which began in the late 19th century in England. The Prairie School detested the current wave of mass production in industrial assembly lines and justified this by claiming that it dehumanized workers and that the process created inferior materials. They reacted by devoting themselves to handcrafting and the craftsman societies (Koning and Eizenberg, 1981). The emphasis of the Prairie school is the following:

- Horizontal expansion of the building as opposed to vertical. Prairie houses were typically two-story buildings with single-story wings. They emphasized horizontality using ribbon windows, suppressed, heavy-set chimneys, gently sloping roofs, and overhangs and horizontal lines.

The following table illustrates the main aesthetic characteristics of functionalism schools of modern architecture.

Table 4. Three main schools developed based on the notion of Functionalism.

	Basic ideas	Main concerns	Architectural Characteristics
Chicago School 1875-1925	-Pioneer in the expansion of Modern Architecture. -Emphasized on the vertical aesthetic.	- Invention of elevators had encouraged vertical building construction.	- Aesthetic implication of steel and Iron. -High rise buildings. - Much severer degree of fire safety.
Bauhaus school 1919-1933	-Embraced the aesthetic theory of functionalism. - Fears about art's loss of purpose in society.	-"*Form follows function*." -The aesthetics of machine. - Simple forms	- Order, regularity, and the sense of space, rather than mass predominated. -Free-plan interiors. -Use of concrete, glass and steel; stark white cubes.
Prairie School 1905-1925	- Sympathy with the ideals and design aesthetics of the Arts and Crafts Movement. - Against the new assembly line, mass production.	-Emphasis on horizontal lines. -Low proportions. -Gently sloping roofs and sheltering overhangs. -Visual expression of natural materials.	-The emphasis is on the horizontal expansion of the building. -Generally two-story building. -The idea of abandoning small, boxy rooms in favor of a more open, integrated interior space. - Suppressed, heavy-set chimneys, Ribbon windows, overhangs and gently sloping roofs.

2.2.2. Late Modernism 1945-1972

Further assessment of the aesthetic nature of Modern Architecture revealed another important classification which has been described as Late Modern or Late Modernism. Late Modern Architecture was most fashionable between the period after World War II to early 1970s. Although, its ideals are rectangular forms just as the Modern Movement, nonetheless, Late Modern architects conceive that buildings are not merely simple set of volumes, but masterpiece of sculptural articulations. This is acceptable even when these sculptural forms are simply the result of structural engineering innovations. This study classifies the aesthetic characteristics of Late Modern Architecture in four main categories which are International style, Organic Architecture, Brutalism and Minimalism.

2.2.2.1. The International Style (1920-1965)

The International style was a reaction against the historicist styles and Art Nouveau of the 19th and 20th centuries. It is a clean break from tradition. As it has already been mentioned, the style came to limelight in the United States amid the Nazi prejudice in Germany and the Bauhaus initiated the ideas that culminated it. In the US, the style was associated with upscale buildings. Characteristic of the International style is the emphasis on austerity, clean lines, clinical white colors, bald facades and total rejection of ornaments. The hallmark of the style is its emphasis on volumes rather than mass, so much so that it portrays an aura of lightness and weightlessness using thin curtain walls, open plan spaces, machine aesthetics, up-to-minute innovations in building technology, prefabrications, and the honest use of materials (Nia, H., & Suleiman, 2018 Colquhoun, 1962). The style supports that buildings should be designed to be rational and scientific in their organization which dictated the search for honesty, economy and utility that meets society's new needs while at the same time appealing to the aesthetic taste. Glass and steel, in combination with usually less visible reinforced concrete, are the characteristic materials of construction. Conventionally, roofs are flat and construction is normally of steel frame or reinforced concrete tactically hidden to portray light weight thin fabrication which remained its highpoint.

2.2.2.2. Brutalism

Brutalism was an architectural movement that aimed to redress the Modern Movement. It was also a reaction against the Modern Movement claiming that its scale is frivolous and as a result does not serve the purpose for Architecture. It also suggested that Modern Movement is deficient in its utilitarian functions. Reyner Banham, an architectural critic, was first to coin out the term "Brutalism" to express concern over this in his 1966 publication "The New Brutalism: Ethic or Aesthetic?" Consequently, the movement defined its high points with grandeur, monumentality and heroism and advanced that the Modern Movement should embrace it (Lozanovskam, 2015). Although, Reyner Banham expressed scholarly concern, the French architect, Le Corbusier demonstrated the praxis. Thus, the idea began in France. Brutalism is an architectural philosophy that advocated for a more formal expression where function and materials were honest and exposed. Its strong points are massive use of concrete and repeated angles. According to Royal Institute of British Architects (RIBA), the foremost aesthetic characteristic of Brutalist buildings are:

- Unusual shapes
- Heavy looking materials
- Relatively Small windows
- Massive forms
- Rough unfinished surfaces.

While a high point of the Brutalist Movement on one hand is the continuous repetition of architectural features to generate modules of activity areas which are distinctly recognizable, on the other, concrete is used with immaculate honesty and in its unaffected form. These are a far departure from the earlier delicate and flowery elite Beaux-Arts architectural style. Indeed, the facades of casted concrete were retained without cosmetic coatings. Building materials comprise gabions, glass, brick, steel, and rough-hewn stone. It is imperative here to point out that not all buildings exhibiting an exposed concrete exterior are Brutalist. They may belong to one of a range of architectural styles including the International Style, Constructivism, Postmodernism, Expressionism and De-Constructivism.

2.2.2.3. Organic Architecture (1908 Onward)

Organic architecture is a philosophy that a building and its environment are altogether one and the same. Frank Lloyd Wright developed the philosophy of Organic Architecture to conceptualize the notion that a building evolves from its natural environment. Despite this, it is further expected that there must be harmony between all the parts of the building and that the building must altogether constitute a united whole. The highpoints of Organic Architecture are reflected in the fact that the building is an organism and as such every part of the building – from the fenestrations to the walls, the space to the furniture that fill it – must be true and systemically related to each other. In this way, Organic Architecture reflects the symbiotic ordering systems of nature (Wright, 1954).

From Wright's perspective, organic architecture is a mimic of the nature around us in buildings. Wright asserted that buildings should correspond to time and place and should intricately interweave with its site so much so that the building should "grow naturally" from the site. This aside, Wright was also convinced that all the parts of the building must relate in tandem constituting as a result, an organism. He asserted the use of natural design elements such as water, plants, spacious interiors, natural lighting, and natural building materials to epitomize Organic Architecture (Zevi, 1950). Contrariwise, buildings according to this view should discountenance artificial lighting and building materials. Within this ideological framework, colour choices are also considered imperative and are usually yellows, oranges, and browns reflecting the environment. Wrights ideology of design has crystalized over the years as "Organic" and has been identified as such. Some of the highpoints of this ideology are the following:

- Using natural colors.
- Providing a place for natural greenery.
- One integrating dominant form.
- Revealing the nature of materials.
- The idea that a building should grow from its site.
- Opening up spaces.

Overall, from aesthetic point of view, the term Organic Architecture typifies a symbiotic association between the building and environment. The building cannot be detached from the environment from which it "grows", while the building itself relates with itself in organized rhythm and relationships.

2.2.2.4. Minimalism (1960s- 1970s)

Minimalism commenced following the aftermath of post–World War II Western Arts. It was most conspicuous with American visual arts of the 1960s and early 1970s. This notwithstanding, De Stijl and traditional Japanese design were generally accepted as forerunners of the minimalist movement. In Architecture, minimalism is a reductive ideology preying on Modernism. It has also been seen as a reactionary ideology pinning against abstract expressionism and a transition to post-minimal arts. Minimalist architecture is an attempt to strip-off all "non-essentials" until simplicity is achieved (Cerver, 1997). This does not necessarily mean the total absence of ornamentation but it indicated a condition where nothing else can be removed to improve the quality of design (Bertoni, 2002).

Within this ideology, design elements project the sense of simplicity. Typically, open-plan spatial arrangements, harmonious colors, basic geometric shapes, elements without decoration, natural textures, clean finishes, neat and straight components, large windows and satisfying negative spaces, flat or nearly flat roofs, simple materials, repetitions are used to achieve simplicity. Minimalist architects are not exclusively concerned with the physical aesthetic qualities of the buildings but with spiritual aesthetic and the invisible as well. They do so by hearing from the building and paying attention to space, details, nature, people and materials (Bertoni, 2002).

The following table illustrates the main aesthetic characteristics of four main styles in the Late Modern architecture.

Table 5. Four main categories of the late modern architecture.

	Idea	Major Characteristic	Architectural Characteristics
International style	-Response against historicist styles of the 19th and 20th centuries. -Optimum use of technology and modern materials.	- Curtain walls of glass or prefabricated parts. - Rational organization of a plan. -Open interior spaces. -Volume (usually rectangular)	-Clear articulation of the grid frame. - Precise regularity of a modular pattern. -Rectilinear forms. - Glass and steel.

Organic Architecture	- Promotes harmony between natural world and human habitation. -Building should develop out of its natural surroundings.	-Be inspired by nature and be sustainable, healthy, conserving, and diverse. -Exist in the "continuous present" and "begin again".	-Prairie school style of creating residential homes. -Harmony with the nature. -horizontal lines. -"Grow out of the site".
Brutalism	-To reveal the basic nature of its construction. - Exposure of the building's functions. - To redirect Modern Architecture toward a more monumental form. - Associated with a collective utopian ideology.	-Rough unfinished surfaces -Unusual shapes -Heavy-looking materials -Massive forms - Extensive use of raw concrete. -Concrete are made to reveal the basic nature of its construction.	-Repeated modular elements. - Specific functional zones. - Usually formed with repeated modular elements. - Nclude brick, glass, steel, rough-hewn stone, rough-hewn stone and gabions. - Relatively small windows.
Minimalism	-Response against abstract expressionism. -Simplicity convey the ideas of freedom.	- Traditional Japanese design and De Stijl are predecessors. -Basic geometric shapes. -Natural textures, open-plan spatial arrangements, clean finishes. -Simplicity in form and function.	-Uncomplicated cladding and wall finishes. -Clean, open, light-filled spaces. -Simple detailing devoid of decoration - Simple materials and large windows. -Harmonious colours, Flat or nearly flat roofs.

3. DISCUSSION

Throughout the history of Modern Architecture, there were some fluctuations on aesthetic understanding and the philosophy of aesthetic construction. These resulted in different views in the aesthetic understanding of Modern Architecture which has led to different architectural styles. As was earlier clarified, Modern Architecture, by the ideas it conveyed in its major philosophies such as the house is a machine for living, form follows function and ornamentations is crime aimed at benefiting from the technological assets resulting from the industrial revolution. This is in spite of the fact that Modern Architecture derived its negative reputation by rejecting traditional styles. This study also highlighted some architectural styles of the modern era such as the Arts and Crafts movement, Beaux Arts Architecture, Art Nouveau and the Gothic Revival which seems to logically adopt modern technologies in such a way that their local authenticity can still be seen.

As soon as Futurism and expressionism emerged as architectural methods of construction, it became obvious that this was a significant milestone in the aesthetic understanding of the Modern Architecture. Distortion of form for an emotional effect (which was the Expressionism philosophy of design and the futurism emphasis on the beauty of speed and technology) opened new vistas in the history of Modern Architecture. Thereafter, famous architects (depending on the era) such as Le Corbusier, Walter Gropious, Adolf Loos and Mies van der Rohe have followed the same ideology. The Rationalist, Formalism and Functionalist tendencies were three main factors which were developed from the modernism philosophy of construction.

The study revealed that between 1945-1972 there was another milestone landmarking the history of Modern Architecture;which was Late Modernism. This era, which began after the Second World War, can be classified from an aesthetic point of vew into four main styles. Apart from International style which was the continous logical development of Bauhaus functionalist ideology, the other architectural styles were Brutalism, Organic Architecture and Minimalism; all of which attempted to develop specific aesthetic language to fit modernistic buildings. Overall, Figure 1 below illustrates the chronological development of aesthetic progress in Modern Architecture.

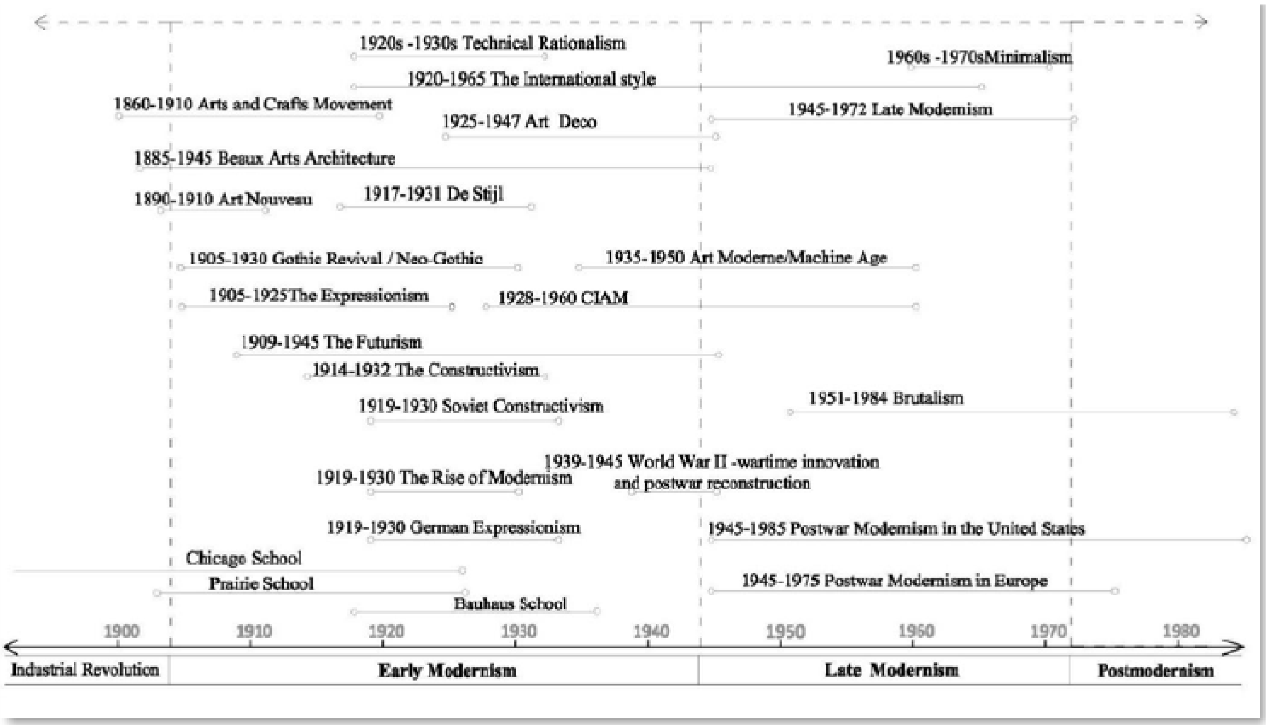

Figure 1. Chronological development of aesthetic progress in Modern Architecture

There have also been several attempts to justify the logic of modernistic ideology from the architectural points of view. This study however revealed that apart from logical aesthetic applications, there were many other factors which led to its failure. As was previously stated, removing ornamentation and conceiving architecture as machine for living was the main and preliminary factor why people's aesthetic curiosity were never satisfied. In this regard, Charles Jencks pointed out that the destruction of the notorious Pruitt-Igoe[2] on July 15, 1972 was in fact "death of Modern Architecture". The building was designed premising on the ideals of CIAM (Congress Internationaux D' architecture Moderne). It epitomizes the beliefs of Modern Architecture in which "good form was to lead to good context (Jencks, 1987; Guzer and Abdi, 2006). Pruitt-Igoe was destroyed owing to vandalization and ultimate rejection by users. In fact, despite enormous spending for maintenance and restoration, the problems with it persisted. Taking its destruction event as a symbol, Charles Jencks asserted the death of Modernism and the beginning of a new period as Post-Modern era. Aesthetic characteristics of postmodernism are other notions that need to be considered for future study.

4. CONCLUSIONS

The study revealed that progressive capitalism and the technological process constitutes the two major reasons for the emergence of Modern Architecture. The study further revealed that the emerging industrialization and the concomitant machine technology brought along with it new possibilities in construction, and in the advancement of new materials, logic and standardization to redirect the course of architectural aesthetics. Thus, it has been put forward that, such attributes as function, standard, efficiency, and self-referential designs are the highpoints of Modern Architecture. It also became clearer from this study that one of the main purposes of Modern Architecture was to set the criteria for architecture based on performance and function to achieve comfort, hygiene, quality of life and health.

[2] *in St. Louis, Missouri*

This study concludes that the Le Corbusier's maxim: "the house is a machine for living" promoted utility, efficiency, economy, accuracy, functionality, technology, and enhanced the love for simple building aesthetics.

The study also revealed that the adoption of standardization in Modern Architecture is significant because it enhanced order, planning and became a foundation for reviewing architectural designs scientifically. It is therefore obvious that it is the foothold upon which good architecture had emerged. Considering this fact, it was highlighted that the major factor which led to the failure of Modern Architecture was its relegation of cultural references. Ignoring cultural values and its symbolic ornamentation for the machine as the standardized method for architectural designing, resulted in the lack of sense of place and lack of place attachment. These have been considered the most important non-aesthetic factor in the failure of Modern Architecture. Overall, this study points out that the interrelation between the quality of life in the modern era and Modern Architecture is an area that needs further studies to answer the question on why Modern Architecture failed to improve the aesthetic quality of life aside from its own unique approaches.

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CONFLICT OF INTERESTS
The authors declare no conflict of interest.

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Microstructure Model for Predicting the Sorptivity of Concrete Mixtures

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ABSTRACT

Durability of concrete structures is determined by the mass transport properties of concrete. The performance of concrete exposed to aggressive environments is a function mainly of the penetrability of the pore structure i.e. the rate of absorption (sorptivity) due to capillary rise. This study involves the development of a predictive sorptivity microstructure model accounting for the type of cement, cement degree of hydration, mixtures proportion, aggregates gradation and packing density, and air content. This paper presents the formulation and validation of a sorptivity model. An experimental program is designed to evaluate the proposed model. Evaluation of the proposed model revealed that the model is a good fit to the experimental data and does not contain outliers or discerning pattern. The corresponding standard error and correlation coefficient are 0.00039 mm/s1/2 and 0.89, respectively. Results of statistical evaluation revealed that the proposed model is significant in its prediction of the outcome, where the p-value was found to be less than 0.001. The proposed predictive sorptivity model can be employed in the design of concrete mixtures to meet specific durability requirements as a priority and ensure quality control. Furthermore, the proposed model can be utilized to improve the durability prediction of concrete mixtures.

Keywords Concrete, Sorptivity, Absorption, Water Penetration, Durability, Packing Density, Porosity, Transport Properties

1. INTRODUCTION

Durability of concrete structures is determined by the mass transport properties of concrete. Numerous research studies have shown that mass transport properties of concrete, namely permeability and sorptivity are directly related to the durability of concrete structures, in which higher sorptivity or permeability leads to less durable concretes [1]. The most important parameter leading to premature deterioration of concrete structures is the access of moisture into the concrete. The transport of liquid through concrete is usually described by absorption and permeability. Absorption is a material property, which reflects the ability of the concrete to transmit liquids by capillary suction to fill the pore spaces available within the concrete microstructure. The rate of absorbed volume of liquids per unit area gives an indication of the pore structure of concrete. The sorptivity test measures the capillary suction of concrete while in contact with water. The increase in the mass of a specimen due to the absorption of water by capillary suction is measured for certain time intervals when the surface of the unsaturated concrete specimen is exposed to water ingress. Therefore, sorptivity is a property related to capillary effects and is defined as the gradient of volume of water absorbed per unit area of section surface and the square root of the absorption time [2]. Sorptivity can be evaluated using Equation 1:

$$M(t) = \rho \ A_f \, S \ t^{1/2} \qquad (1)$$

Where: M(t) is the mass of fluid uptake; t is time; ρ is the density of fluid; A is the cross sectional area in contact with fluid; and S is the sorptivity. According to ASTM C1585 [3], sorptivity is determined for each mix using linear regressive analysis, in which the absorption, $M(t)/\rho A$, at certain time intervals is plotted against the square root of time and then the slope of the best fit line is determined.

The rate of liquid penetration into the concrete depends on its pore structure, which depends on the materials and mixture proportions. Therefore, the main influential variables include the water-to-cement ratio of the concrete, the degree of cement hydration, the amount of air, and the use of supplementary cementing materials [4]. Numerous researches have revealed that an increase in the water to cement ratio results in an increase in the void content and consequently a reduction in both the strength and durability of hardened concrete [2,5]. The degree of cement hydration depends mainly on the type and amount of cement paste, age of concrete, and curing conditions. The older the concrete the greater the amount of hydration, which leads to a more highly developed pore structure. Proper curing of concrete is necessary to ensure the existent of a sufficient amount of water for cement hydration to occur over time. Research has also shown that the packing density of the aggregates used in concrete impacts the hardened properties of concrete [5,6]. Dense packing of the aggregates through improved proportions and gradations would lead to an increase in strength and reduction in the porosity of hardened concrete due to the reduction in the amount and size of voids in concrete [5].

Therefore, in order to design for a more durable and less permeable concrete at the concrete mixture proportioning stage, it is necessary to develop a model which can predict the rate of water absorption into concrete. This paper presents the research findings and is divided into two main parts. The first part provides the mathematical description of the proposed sorptivity model. The second part presents the evaluation and model validation protocol adopted, which includes an experimental program carried out by the author.

2. SORPTIVITY MODEL DEVELOPMENT

2.1. General Form and Main Variables

The proposed model for predicting the sorptivity is function of concrete mixture and comprises of: cement hydration model to account for the chemical composition of cement and the degree of cement hydration, and variables accounting for the packing density of aggregates, capillary porosity and air voids. Accordingly, the general form of the sorptivity model is a function of the following main variables (Equation 2):

$$S = F\ (\alpha,\ \phi_{agg},\ w/c,\ V_a) \qquad (2)$$

Where: α is the degree of hydration of cement; ϕ_{agg} is the packing density of aggregates; w/c is the water to cementing materials ratio; and Va is the volume fraction of air entrapped and/or entrained relative to total volume of the mix.

2.2. Cement Hydration Model

Portland cement reacts with water to form two major products, calcium silicate hydrates and calcium hydroxide. Numerous researchers have studied and modeled cement hydration as it provides the critical link for concrete evolution [7]. The degree of cement hydration is defined as the ratio between the quantity of hydrated cement to the original quantity. It is influenced by the cement composition and fineness, the water-to-cement ratio, mineral admixtures, concrete age, temperature, and moisture content [8].

Research has revealed the existence of a linear relationship between the compressive strength of concrete and the degree of cement hydration that depends on the water to cement ratio [9]. With other variables constant, an increase in the degree of cement hydration leads to an increase in strength and durability of hardened concrete. Research has also shown that cement starts hydrating and gaining strength when the degree of cement hydration (α) reaches a threshold value called the critical degree of hydration (αcr). For Portland cement, αcr can be estimated by multiplying w/c with a constant, k, of 0.43 [10]. Limited number of researchers have developed strength prediction models that relate the compressive strength of concrete to the degree of cement hydration [6,8,11]. Since an increase in α beyond αcr results in a linear increase in strength and a reduction in concrete permeability, in this study α is related to Sorptivity (S) using the following relationship (Equation 3):

$$S \propto 1/(\alpha - \alpha_{cr}),\ \alpha > \alpha_{cr} \qquad (3)$$

For prediction of α, the Schindler and Folliard [8] cement hydration model was adopted in this study because of its general form, completeness, and good predictions.

2.3. Capillary Pores and Air Pores

Concrete w/c influences the amount of capillary pores, in which an increase in w/c results in an increase in capillary pores leading to a reduction in strength and an increase in permeability [7]. In addition, the amount of air pores, either entrapped or entrained, reduces strength and increases permeability. Popovics' relationship between strength and amount of pores, a modification of Abram's model [12], has shown a high degree of predictability [6,13] and was therefore, adopted in this study (Equation 4):

$$S \propto B^{(w + V_a)/c} \qquad (4)$$

Where: (w+Va)/c is the weight fraction of water and air relative to cementing materials in the concrete mix; and B is a calibration constant accounting for the shape of the tested specimen and the test conditions.

2.4. Packing Density

The packing density property gives an indirect measurement of concrete porosity and accounts for both the gradation and proportions of aggregates and cement [14]. Research studies have revealed that the optimum packing density of aggregates leads to optimum mechanical properties and durability through the reduction of concrete porosity [15,16,17]. More specifically, higher packing density of aggregates leads to higher strength and improved durability of hardened concrete through reduction in the w/c while maintaining the same workability [5]. Research has also shown that strength is function of the ratio of the packing density (aggregate volume fraction) in a concrete mixture to its maximum packing density, ϕ/ϕmax [5]. Accordingly, in this study, sorptivity is related to the packing density ratio of aggregates as follows (Equation 5):

$$S \propto (1 - \phi/\phi_{max}) \qquad (5)$$

Where: ϕ is the volume fraction of aggregates; and ϕmax is the maximum packing density of aggregates. An increase in ϕ/ϕmax should lead to a reduction in concrete sorptivity when other variables are fixed.

The maximum packing density is function of the size, shape, volume fraction of solid particles in the mix, and the method of compaction [5,16]. Maximum packing density can be estimated using the Compressible Packing Model (CPM), developed by de Larrard [5], which was revealed to give good predictability for concrete mixtures.

2.5. Sorptivity Model Final Form

Combining the relationships presented (equations 2 to 5) and using statistical regression, yields the following proposed fundamental model for predicting the sorptivity of concrete (Equation 6):

$$S = A/(\alpha - \alpha_{cr})[B^{(w + V_a)/c} (1 - \phi/\phi_{max})], \ \alpha > \alpha_{cr} \quad (6)$$

The calibration constant A depends on the nature of the Sorptivity test and its unit is in mm/s1/2. The calibration constant B is a dimensionless term, which depends on the shape of the tested specimen and the test conditions. The calibration constants A and B are determined by minimizing the model standard error between the model predictions and measured experimental data. All other ratios given in equation 6 are dimensionless terms.

3. EXPERIMENTAL PROGRAM

The experimental program was developed to evaluate the applicability and accuracy of the proposed model in predicting the sorptivity of concrete. Traditional design variables typically used in proportioning concrete mixtures, including the water to cementing materials ratio, amount of water content, and air entrainment, were adopted for the design of the experimental program. A high range water reducer (HRWR) was also utilized to improve the workability of dry mixes.

3.1. Concrete Mixture Design

A total of six concrete mixtures given in Table 1 were proportioned following ACI 211 [18] guidelines with w/c of 0.25, 0.3, and 0.4. For the dry mixes, the amount of HRWR was varied to achieve a slump between 75 and 100 mm to ensure an adequate level of workability while avoiding segregation. The cementitious materials content ranged from 375 to 600 kg/m3. The table also presents the amounts of cement, coarse aggregate, (CA), fine aggregates (FA). Air entraining admixture (AEA) was added to mix # 4 and mix # 5 at a rate of 80 ml/100 kg of cement.

3.2. Materials

This section presents the details for all materials used in concrete mixes including their technical properties. Both of the coarse aggregate (CA) and fine aggregate (FA) are crushed limestone. The maximum aggregate size of CA is 19 mm. FA consist of well-graded local sand. Bulk density, specific gravity, and absorption for CA and FA were determined following ASTM C127 [19] and ASTM C128 [20] standards, respectively. Specific gravity, absorption value and bulk density for the 19 mm CA are 2.68, 1.2% and 1600 kg/m3, respectively. Fineness modulus, specific gravity, absorption values and bulk density for the FA are 2.82, 2.67, 2.5% and 1800 kg/m3, respectively. The particle size distributions of CA and FA were measured and calculated using the sieve analysis procedure and were found to conform to the ASTM C136/C136M [21] specification requirements, as shown in Figure 1. The cement used is Type I/II Portland cement with a specific gravity of 3.15 and meeting ASTM C150/C150M [22]. The HRWR used is Master-Glenium 7920 (from BASF), a Polycarboxylate type of admixture, which meets the requirements of ASTM C494/C494M [23] and the air-entraining admixture used meets the requirements of ASTM C260/C260M [24].

Table 1. Concrete Mixture Design Composition

MIX #	w/c	Water (kg/m^3)	Cement (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	HRWR (ml/100 kg cement)
1	0.30	150	500	960	852	606
2	0.25	150	600	960	852	589
3	0.40	150	375	960	960	370
4	0.40	150	375	960	852	215
5	0.40	184	460	960	687	0
6	0.40	205	513	960	693	0

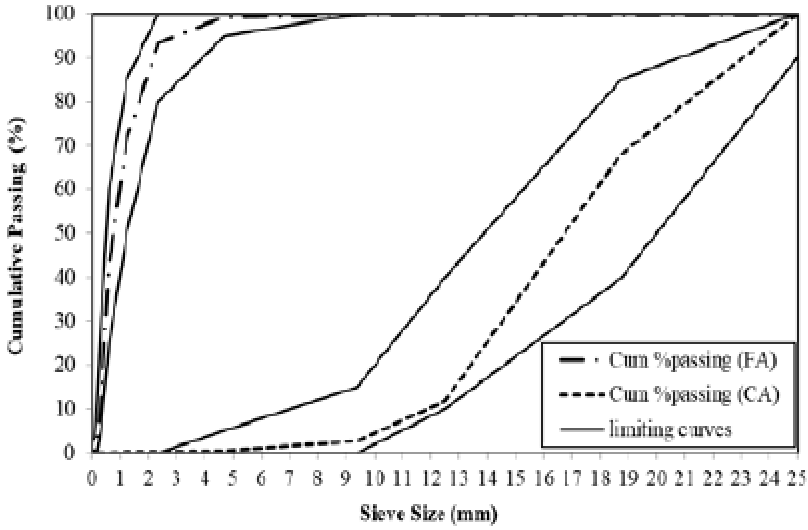

Figure 1. Aggregates Particles Size Distribution

3.3. Experimental Procedure

The same experimental procedure was followed for all concrete mixtures and includes mixing, placing, consolidating, curing and testing. Mixing and placing followed ASTM C192/C192M [25]. The slump and air content were measured for each concrete mixture as per ASTM C143/C143M [26] and ASTM C231/C231M [27], respectively. After casting and placing, the specimens were immediately sealed and moved to a standard curing room with relative humidity in excess of 95% and temperature of 23 ºC. For every mixture, 100 x 200 mm (4 x 8 in.) standard cylinders were cast, compacted by rodding and surface finished in accordance with ASTM C192/C192M [25]. The concrete compressive strength was also evaluated at 28 days following ASTMC39/C39M [28] to ensure good concrete performance and achieving mix design proportioning requirements. Conducting the sorptivity test, which includes cutting, conditioning, and testing, was done in accordance with ASTM C1585 [3].

3.4. Sorptivity Samples Preparation and Testing

In accordance with ASTM C1585 [3], Sorptivity specimens were prepared by cutting discs of 100 ± 6 mm in diameter and 50±3 mm in length. Using a Saw, discs were cut from the interior of the 200 mm long cylinders to ensure that the specimens are representative samples of the concrete and to ensure consistency. Prior to the test, the specimens were placed in a desiccator oven at a temperature of 50 ±2 ºC and a relative humidity RH of 80 ± 3% for 3 days. The perimeter of each disc was then sealed using electric tape. At the start of the test, the disc was placed in contact with water at one end while open to air at the other end. Mass gain due to water sorption was measured at certain intervals for the first six hours. Figure 2 presents the schematic diagram of the water sorptivity test setup.

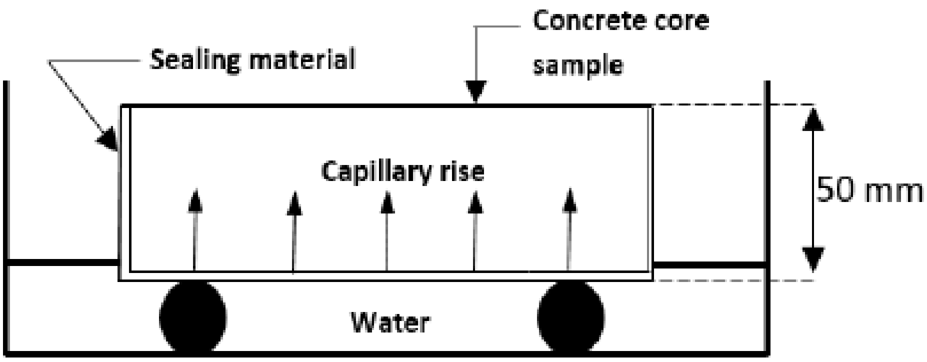

Figure 2. Schematic Diagram of the Water Sorptivity Test

4. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed sorptivity model requires determining of the calibration constants. Model Calibration was carried out by minimizing the standard error (σ) between the model predictions and the measured experimental data. The standard error, which provides a global assessment of the model predictions, is defined in Equation 7 [29]:

$$\sigma = \{\Sigma[S_m(i) - S_{exp}(i)]^2 / (n - p)\}^{1/2} \quad (7)$$

Where parameters $S_m(i)$ and $S_{exp}(i)$ refer to the model and experimental sorptivity values that correspond to mix i, respectively. Parameters n and p refer to the number of tested points and the number of model constants, respectively. This application provides an assessment of the goodness of fit and the soundness of the proposed model. In addition, the correlation coefficient (R2), which provides a measure of the proportion of model variability, was also calculated. Such measures permit assessment of the capabilities of the proposed model in predicting the trends reported in the literature. Using the initial absorption (up to 6 hours) experimental data obtained in this study, the initial rate of absorption was determined for each mix using linear regressive analysis as outlined in ASTM C1585 [3]. Consequently, the proposed sorptivity model was calibrated and the calibration constants A and B were found equal to 0.00021 mm/s1/2 and 371, respectively. The corresponding standard error and correlation coefficient were 0.00039 mm/s1/2 and 0.89, respectively.

Table 2. Results of Experimental Testing

MIX #	Slump (mm)	Air Content (%)	Compressive Strength (MPa)	Sorptivity ($mm/s^{1/2}$)
1	80	2.2	97.0	0.00088
2	95	3.0	99.4	0.00073
3	75	1.5	72.1	0.00110
4	90	6.4	45.6	0.00294
5	65	3.5	55.8	0.00181
6	90	2.2	55.8	0.00123

Table 2 presents the experimental results for each mix, which includes the average values for air content, slump, compressive strength at 28 days, and sorptivity. As shown, all the concrete mixes achieved compressive strengths exceeding 40 MPa, which confirms good concrete performance.

Figure 3 is a visual illustration of the sorptivity results obtained for each mix. As expected, mix # 2 having the lowest w/c of 0.25 gave the highest compressive strength and the lowest sorptivity value. This is followed by mix # 1 having a w/c of 0.3 resulting in the second highest compressive strength and consequently the second lowest sorptivity value. Mix # 4 gave the lowest compressive strength and highest sorptivity value due to the higher air content (6.4%) in comparison with other mixes. This is followed by mix #5 with an air content of 3.5%. Mixes #3 and 6 are similar as they both have the same w/c and do not contain entrained air and HRWR. However, mix #3 gave better results due to a higher packing density ratio for the aggregates (ϕ/ϕ_{max}) resulting in less amount of voids.

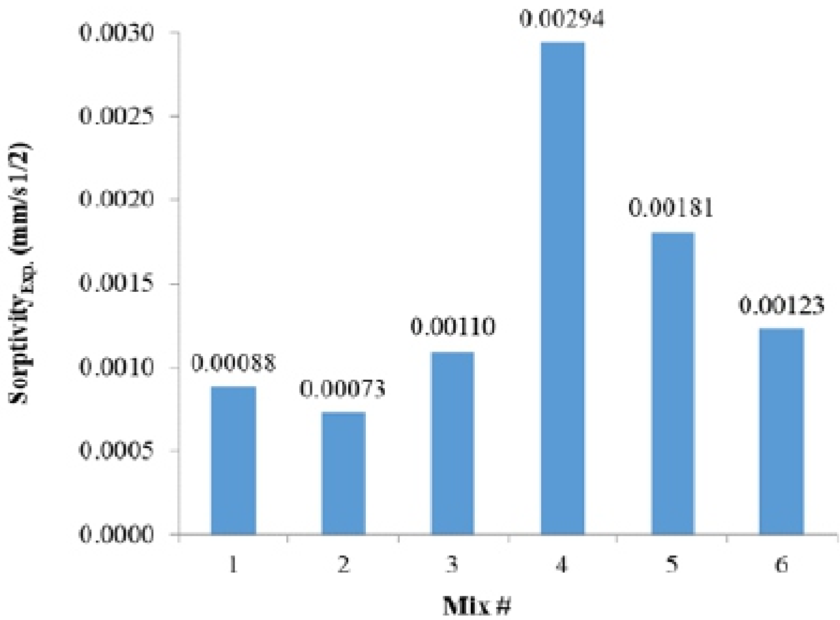

Figure 3. Sorptivity Experimental Results

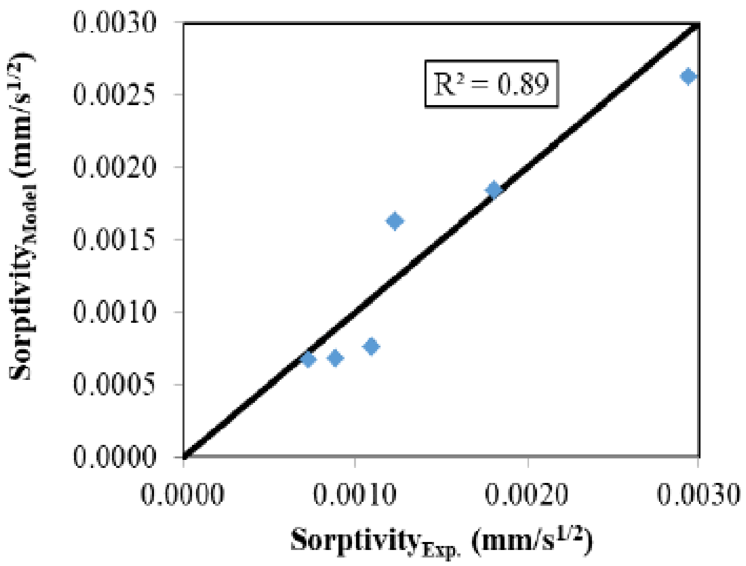

Figure 4. Sorptivity Model vs. Experiment .

Figure 4 shows the goodness of fit of the proposed model in comparison to the measured experimental data. The corresponding standard error and correlation coefficient were 0.00039 mm/s1/2 and 0.89, respectively. These results provide evidence of the model ability to predict the sorptivity of concrete. The soundness of the model was also evaluated through comparing the predicted sorptivity values to the residual values as shown in Figure 5. Results reveal no visible patterns or outliers, which confirms the good predictability of the proposed model. In addition, statistical evaluation results reveal that the proposed model is significant in outcome predictions. The model p-value is found to be less than 0.001.

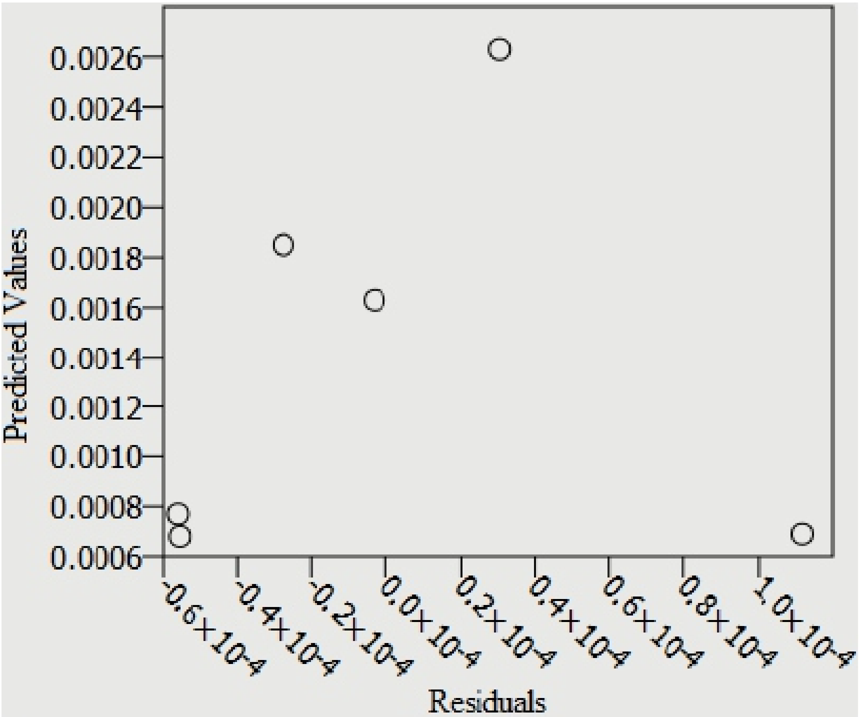

Figure 5. Model Assessment- Residual Plot

5. CONCLUSIONS

In this study, a microstructure sorptivity model for predicting the rate of water absorption in concrete has been formulated, calibrated and validated. The sorptivity model is characterized by the following main features:

- Packing density was incorporated into the sorptivity model to account for particles gradation and mixture proportions.
- A cement hydration model developed by Schindler and Folliard [8] was adopted and incorporated into the sorptivity model to account for the chemical and mechanical properties of cement.
- Concrete capillary pores and air pores (entrapped and entrained) were modeled through incoporating the relationship developed by Popovics [13].

Model evaluation revealed the following conclusions:

- The sorptivity model provides a good fit to the experimental data. In addition, it does not contain outliers or any discerning pattern.
- The standard error is 0.00039 mm/s1/2 only. The corresponding correlation coefficient is greater than 0.89.
- A statistical model evaluation revealed that the proposed model is significant in its prediction of the outcome. The model p-value was found to be less than 0.001.

Model calibration constants A and B depend on the nature of the Sorptivity test, and the shape of the tested specimen and test conditions, respectively. These constants were determined by minimizing the model standard error between the model predictions and measured experimental data. It should be noted that the values determined for these constants are applicable for cylindrical specimens tested following the ASTM standards. Re-calibration of these constants will be required for different testing methods and specimen shapes.

This predictive sorptivity model can be utilized in the design of concrete mixtures to meet specific durability requirements as a priority and ensure quality control before concrete is cast. Furthermore, the proposed model can be utilized to improve the durability prediction of concrete mixtures.

Notations

A and B: calibration constants
Af : cross-sectional area in contact with fluid
c, w: quantity of cement and water in the concrete mix, respectively
M(t): the mass of fluid uptake
n: number of test points
p: number of model constants
S Sorptivity
Sm(i), Sexp(i): model and experimental sorptivity values corresponding to mix i, respectively
t: time
Va : volume fraction of air in the concrete mix
w/c: water to cementing materials ratio
α degree of hydration of cement
αcr: critical degree of hydration of cement
ρ: density of fluid
ϕ: volume fraction of aggregates
ϕmax: maximum packing density of aggregates

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Seismic Assessment and Retrofitting of Existing RC Structures: Seismo Struct and Seismo Build Implementation

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ABSTRACT

Many existing structures require seismic retrofitting based on the latest findings and standards. Most of the works presented in the literature have considered the effect of different retrofitting solutions on the seismic behavior of the structures. Therefore, a comprehensive comparison of these techniques is needed to select the most effective one. Hence, in this paper, we present a comparative study of the most useful retrofitting techniques of RC structures, using the recent and updated versions of the standards and design codes. The merits and weaknesses of the most useful retrofit techniques and the available approaches are presented and demonstrated, which utilizes SeismoStruct and SeismoBuild. A 2-story RC building with the lack of transversal and longitudinal reinforcements is retrofitted by some techniques such as RC jacketing, RC walls, and FRP wrapping. The structural response of the retrofitted buildings is compared with the initial one. The comparison of the results shows that using RC walls at the perimeter of the existing buildings is the most efficient way in reducing demand capacity ratio (DCR) of other structural members, maximum roof displacements, and building fundamental period. The results of the pushover analysis of the buildings retrofitted by RC jackets and RC walls indicate a significant increase in the capacity curves.

Keywords Retrofitting, RC Jacketing, FRP Wrapping, RC Walls

1.INTRODUCTION

Earthquake engineering has been developed adequately in recent years, to ensure that well-detailed, recently designed buildings usually show enough strength, stiffness, and ductility to resist severe earthquake ground motion. Most of the existing buildings were built many years ago, when engineering science was not at today's level of understanding, and the building codes were less rigorous. Hence, for the buildings constructed according to older codes, the focus had been put only on the vertical gravity forces, with limited or no concern for the lateral resisting system [1].

Besides, the accelerated progress in all sciences, particularly earthquake engineering during the last decades, has completely changed the design philosophy and codes. Hence, the vast majority of the structures are vulnerable in high-intensity seismic actions and show vital needs to structural upgrading and retrofit, i.e., lack of stiffness, ductility, or resistance to lateral loads and soft stories [2]. Table 1 illustrates the comparison of the most useful retrofit and strengthening techniques for RC buildings. Most of the methods provide an increase in the member's strength and the ductility while using FRPs and steel plates do not affect the structural stiffness. The base isolation system decreases the seismic demand of the structure and does not modify the capacity [3].

Table 1. Comparison of the useful retrofitting techniques

	Strength	Stiffness	Ductility	Seismic Demand
RC Jackets	✓	✓	✓	
New RC walls	✓	✓	✓	
Steel Bracing	✓	✓	✓	
FRP Wrapping	✓		✓	
FRP Laminates	✓			
Steel Plates	✓		✓	
Seismic Isolation				✓

Ten rehabilitation methods tested by Ramírez [4] showed that concrete jackets are easy to construct and are one of the most useful and cost-efficient techniques; Vandoros and Dritsos, [5] with an experimental study proved that RC jacketing and CFRPs increased the columns' strength, and ductility considerably. Also, RC jacketing increases member stiffness. Krainskyi et al., [6] examined ten strengthened RC columns with the same design procedure, but under various loadings, and noted that the capacity increased approximately 290% by doubling the columns' cross-sections. The studies carried out by Balsamo et al., [7] proved that FRP-wrapping enables the development of large-displacement or chord rotation ductility parameters. Ferracuti et al. [8] investigated the behavior of FRP-retrofitted RC frames under seismic actions and showed that the activation of brittle failure modes, for instance, soft-story mechanisms, may be prevented using this method.

Folic et al. [9] studied the impact of adding shear walls for seismic strengthening of old buildings made up of RC frames with insufficient resistance to lateral load. They demonstrated that adding shear walls could successfully improve horizontal rigidity, bearing capacity, ductility, and dissipation capability of seismic energy. Most of the works presented in the literature have been conducted to explore the effect of different retrofitting solutions on the seismic behavior of the structure. However, the literature needs a comprehensive comparison of these techniques. Hence, in this paper, we present a comparative study between some of the most useful retrofitting techniques of RC structures, using the recent and updated versions of the standards and design codes.

2. MODEL DESCRIPTION

The building under consideration in this paper is a 2-story RC building with plan dimensions 11m × 14m and an average inter-story height of 3m, see Figure 1 and Figure 2. The average height of the slabs is 30cm. The majority of beams feature typical dimensions 0.2m × 0.5m with an average length of 4m. There are two types of columns whose dimensions are 0.4m × 0.4m with the longitudinal reinforcement area ratio 0.5% and 1.0m × 2.0m with the longitudinal reinforcement area ratio 0.8% and stirrups ∅6mm@25cm. All the sections are without sufficient longitudinal and transverse reinforcement. The longitudinal and transversal reinforcements are considered constant along with the elements' height.

The majority of beams feature typical dimensions of 20cm × 50cm. Different longitudinal reinforcement is introduced in the middle of the beam and at its two edges, while the transversal reinforcement consists of ∅10mm@15cm stirrups along the member length. The beams' structural details include u2Ø16mm, l4Ø16mm, s2Ø14mm for the reinforcement of the middle part, and u4Ø16mm, l2Ø16mm, s2Ø14mm at the two edges. The slabs' top and bottom reinforcement are typically equal to ∅10mm@10cm.

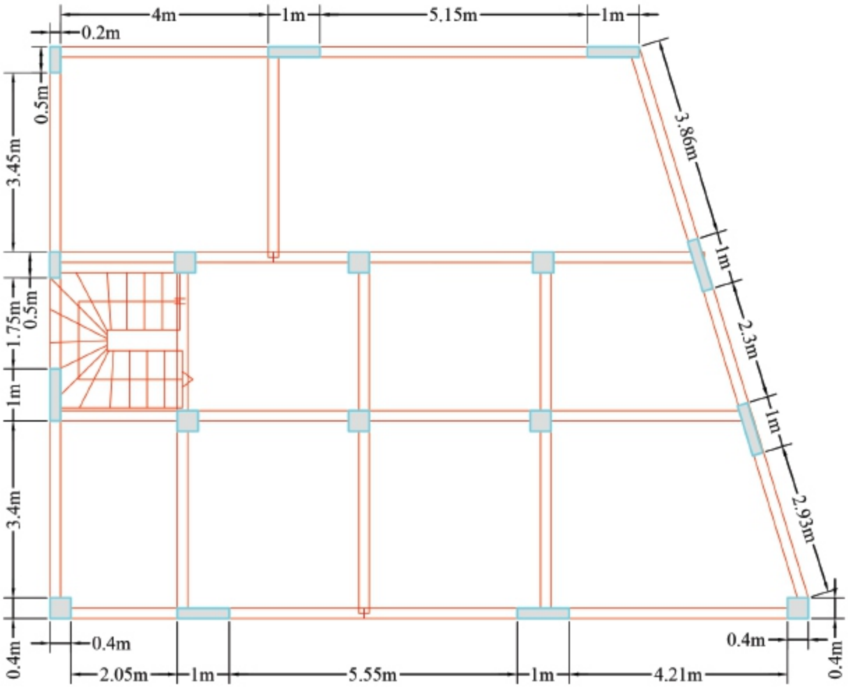


Figure 1. Plan view of the first and second floors

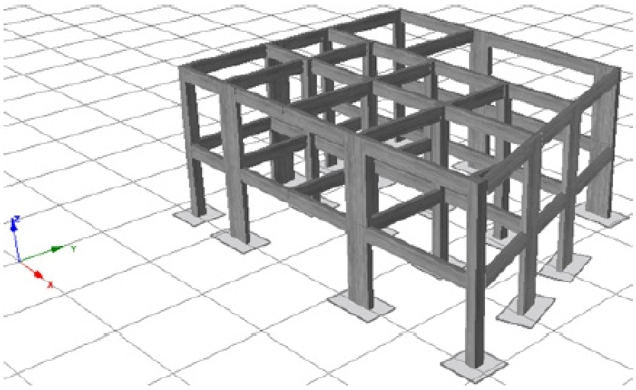


Figure 2. 3-D view of the building

The knowledge level achieved from an extended in-situ inspection or as-built drawings determines the proper method of analysis, as well as the values for the confidence factors (CF). The CF considered 1.20 in this research.

The material of longitudinal reinforcement steel in SeismoStruct is defined by Menegotto and Pinto (1973) model [10]. The Mander et al., (1988) [11] concrete model is used for both the existing and the new/retrofitted members. The confinement effect is a function of section geometry and the longitudinal and transversal reinforcement layout. Expected (mean) strength of the existing concrete strength (f_{cm}) is estimated 20MPa, with a lower-bound strength of 16MPa which is the mean minus one standard deviation $(f_{cm} - \sigma)$. The new concrete grade is C25/30 $(f_{ck} = 25MPa)$. For the existing and new longitudinal and transversal reinforcement steel, Class S400 and Class S500 are chosen, respectively. The material safety factors for the concrete and steel are $\gamma_c = 1.5, \gamma_s = 1.15$ respectively. The slabs are modelled as the rigid diaphragm, and beam-column joints' end rigidity has been taken into consideration. Cross-sections behaviour is modelled by using the fiber model, meaning that each fiber is associated with a uniaxial stress-strain relationship [12].

The contribution of gravity loads to the effective seismic weight is obtained by the combination rule established in equation (1) of EN 1998-1 (2004) [13].

$$\sum_{j\geq 1} G_{k,j} \text{ " + " } \sum_{i\geq 1} \psi_{E,i}\, Q_{k,i} \qquad (1)$$

With $\sum_{j\geq 1} G_{k,j}$ accounting for the summary of dead loads and the combination coefficients $\psi_{E,i}$ take into account the likelihood of the live loads ($Q_{k,i}$) not being present over the entire structure during the earthquake. Permanent loads (G) for the slabs, cantilevers, and stairs are 5.10 KN/m^2, 7.26 KN/m^2, and 5.1 KN/m^2, respectively. Live loads (Q) for slabs, cantilevers, and stairs are 2.00 KN/m^2, 2.50 KN/m^2, and 2.00 KN/m^2, respectively. Permanent and Live loads coefficients are 1.00 and 0.30, respectively. According to EN1998-3 Section 2.1, performance requirements refer to the state of damage in the structure defined through three limit states, namely Near Collapse (NC), Significant Damage (SD), and Damage Limitation (DL) [14]. To draw the elastic and design pseudo-acceleration response spectra shown in Figure 3, the damping ratio considered 5.0%, and the Importance Class II, PGA is 0.160g for the return period of 475 years, and soil class B of type 1, according to EN1998-1 [13].

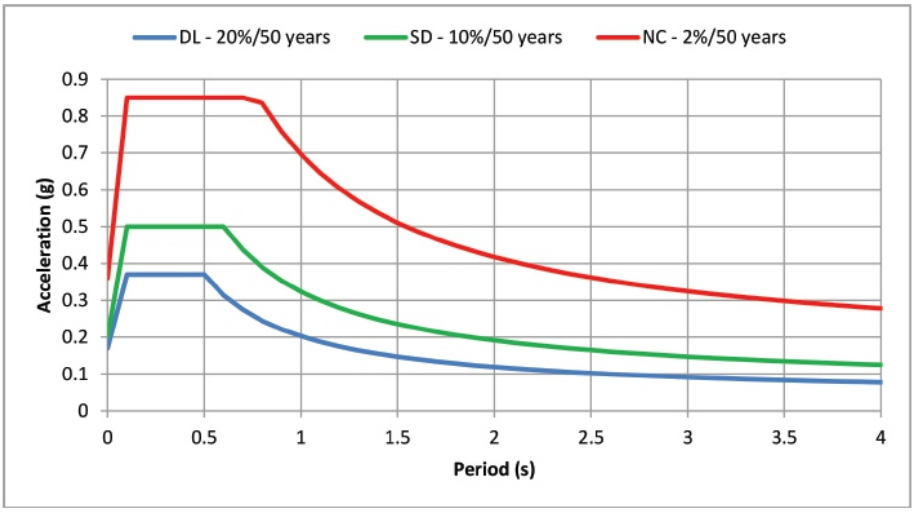


Figure 3. Code-based Spectra for the limit states DL, SD, and NC

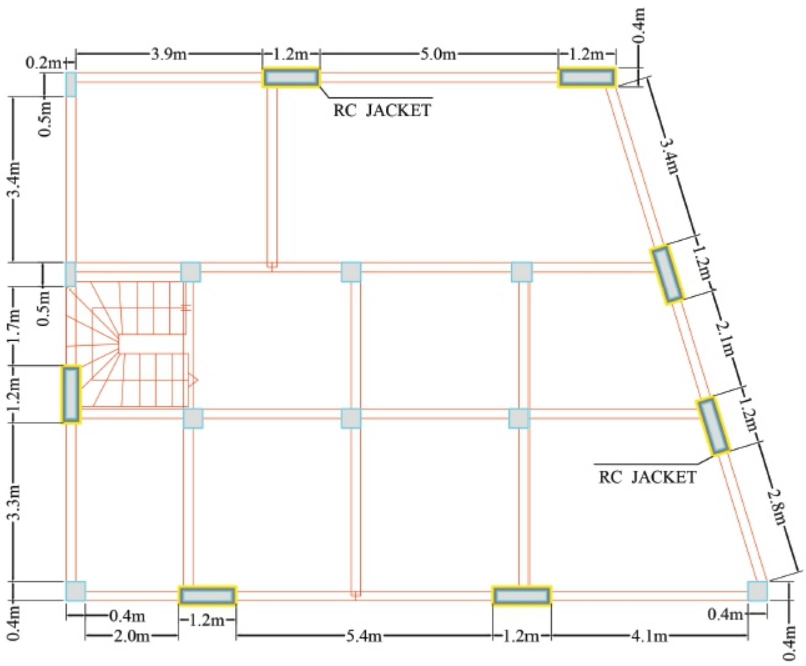


Figure 4. Retrofitting scheme with RC jackets

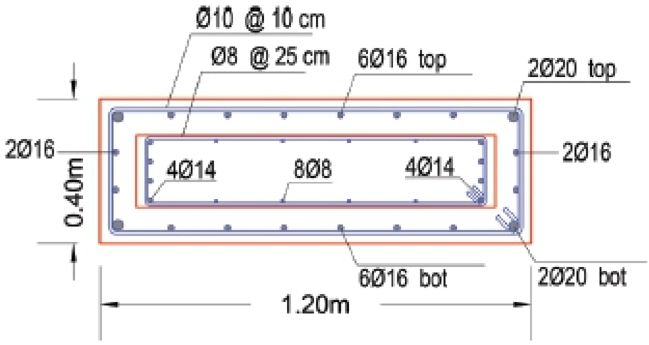


Figure 5. Layout of the jacketed sections

2.1. Retrofitting with RC Jackets

This method includes the additional RC layer outside the perimeter of the existing member using longitudinal and transversal reinforcements. The jacket's concrete grade and the reinforcement steel grade is C25/30, and B500c respectively. The longitudinal reinforcement of a typical jacket could be 4Ø20+4Ø16, although there has been a significant increase in the shear reinforcement of the columns with stirrups of Ø10/10. A significant increase in strength, ductility, and stiffness of the existing members can be achieved by applying this technique. A decrease in seismic demand of other members that are not retrofitted takes place, so strengthening of some structural members may be adequate [15]. Figure 4 and Figure 5 show the retrofitting scheme and layout of the jacketed section, as they were modeled in SeismoBuild.

2.2. Retrofitting with FRP Wrapping

FRP is a composite material made up of a polymer matrix reinforced with fibers. The fibers are usually carbon (CFRP), glass (GFRP), aramid (AFRP), or rarely basalt. FRP materials are commonly applied to existing RC members as external reinforcement due to their high tensile strength and low weight (compared to conventional steel) to increase their flexural and shear strength [16]. It is noted that the strengthening of structural members with FRPs, though considerably increases their strength, does not change their stiffness, and does not affect the stiffness distribution of the entire structure. As it is shown in Figure 6, the retrofit is carried out in all failed columns in code-based checks and with one layer of a relatively strong FRP wrap (SikaWrap 600C). The characteristic and nominal values of the fiber thickness are 0.331mm, tensile strength 3800MPa, tensile modulus 242000MPa, and the elongation 1.55%.

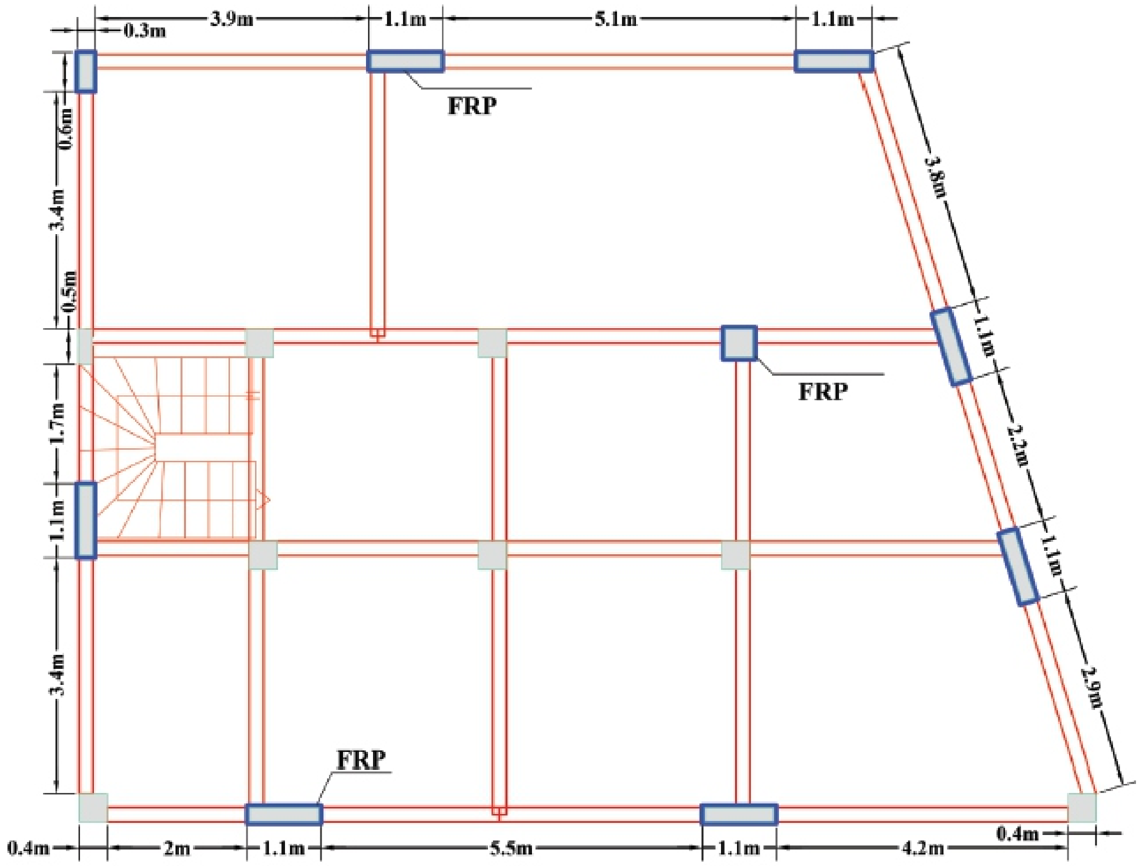


Figure 6. Retrofitting scheme with FRP wrapping

2.3. Retrofitting with RC Walls

RC walls can have a very beneficial effect on the seismic performance of existing buildings, providing a significant increase in strength, stiffness, and ductility. Because of the substantial stiffness of the shear walls concerning the columns, the new walls are usually added in the symmetric scheme, in order to prevent torsional effects in the seismic behavior, and in the entire height of the building, in order to prevent significant irregularities in elevation [15]. RC walls may be added either externally, in the perimeter of the building, or internally, inside the building bays, usually surrounding the existing columns. The seismic demand on the other vertical structural members of the building significantly reduced since the walls can undertake most of the base and the story shears. Hence, new walls are commonly introduced without the strengthening of the other existing columns [12]. As it is shown in Figure 7, the retrofit is carried out with seven new RC walls with two types of cross-sections at the perimeter and extended at the full height of the building. Figure 8 shows the reinforcement layout of RC walls.

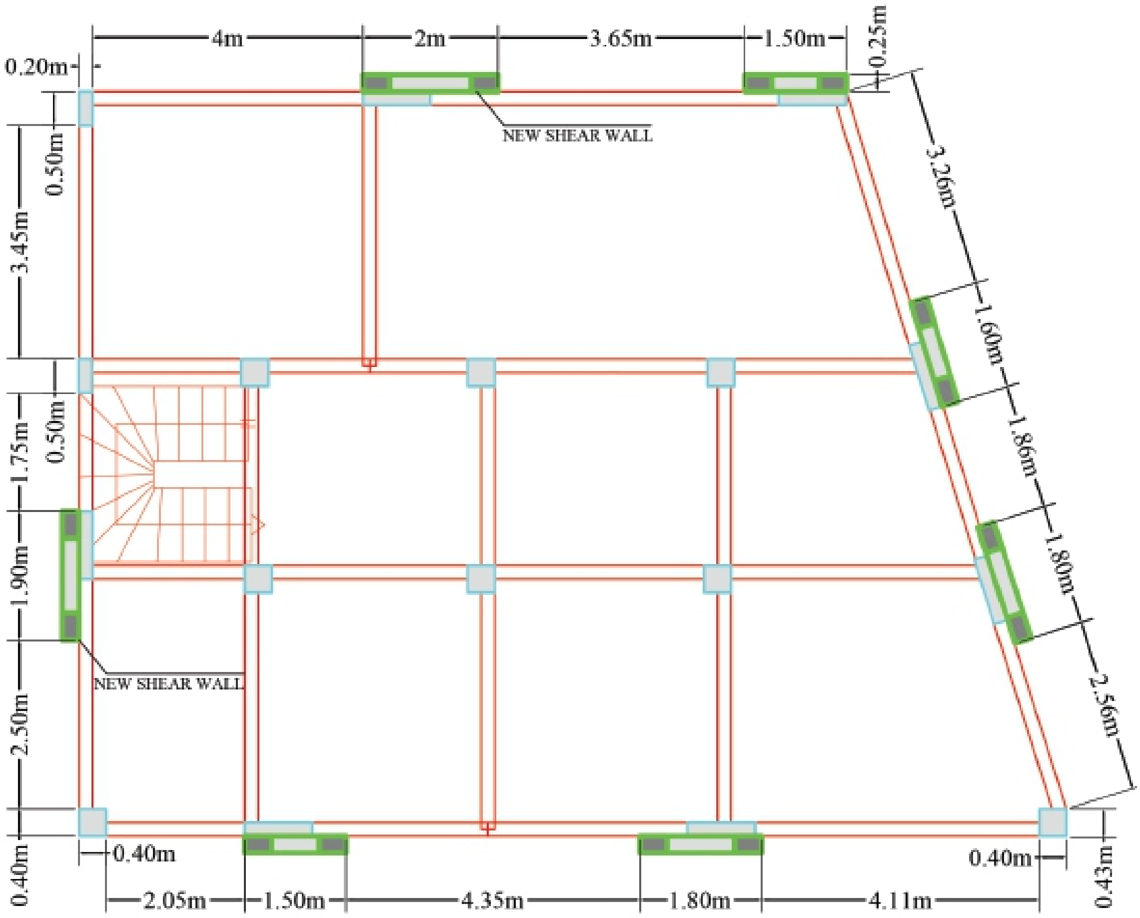


Figure 7. Retrofitting scheme with RC walls

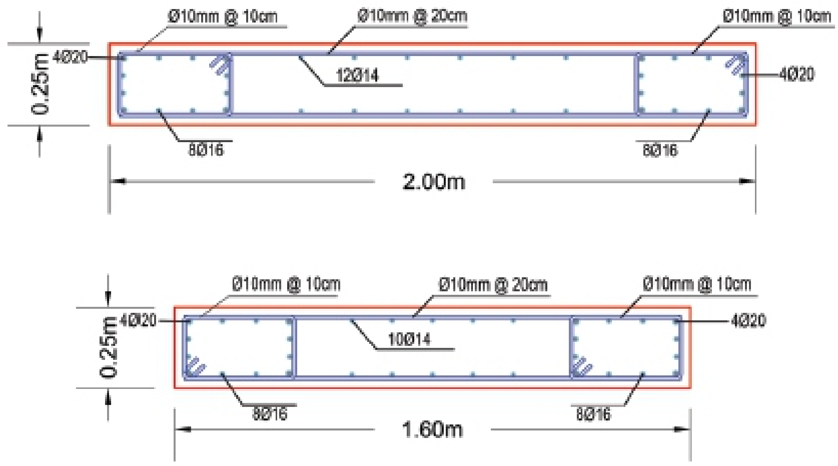


Figure 8. Layout of RC wall sections

3. ANALYSIS AND CODE-BASED CHECKS

According to Eurocode 8, Part 1 and 3, the effects of the seismic action along with the effects of the permanent and variable loads are evaluated by using one of the following methods [13,14]:

1. Lateral force analysis, subject to limitations specified in EN 1998-1:2004 Section 4.3.3.2.1 with the addition of Section 4.4.2 of EN 1998-3:2005;
2. Modal response spectrum analysis, subject to limitations specified in EN 1998-1:2004 Section 4.3.3.3.1 with the addition of the conditions specified in Section 4.2 of EN 1198-3:2005;

3. Non-linear static (pushover) analysis, according to Sections 4.3.3.4.2.1 of EN1998-1:2004 and 4.4.4 of EN 1998-3:2005;
4. Non-linear time history dynamic analysis, according to the procedure of Section 4.3.3.4.3. of EN 1998-1:2004;
5. q-factor approach, as described in EN 1998-1:2004 Section 4.3.3.2 or 4.3.3.3, as appropriate.

In this paper, the eigenvalue, pushover, and dynamic analysis and the code-based checks have been carried out by using SeismoStruct and SeismoBuild software.

3.1. Nonlinear Static Analysis

Pushover analysis is carried out under constant gravity loads, and increasing lateral forces applied at the location of the masses to simulate the inertia forces induced by the seismic action [17]. The introduced vertical loads applied to the 3D model, in addition to incremental loads, are equal to 1.0G+0.3Q. The horizontal load pattern may be applied with different load distributions, i.e., uniform, modal, and adoptive patterns in both positive and negative directions or simultaneously by employing the 30% rule combinations [18].

Each pushover analysis leads to a capacity curve, which is a relationship between the total base shear and the control node horizontal displacement. The centre of mass at each floor may be considered displaced from its nominal location in each direction by an accidental eccentricity equal to 5% of the floor-dimension perpendicular to the direction of the seismic action [19].

3.2. Chord Rotation Capacity Checks

The structural demand associated with specified target displacement should satisfy the verification criteria. Chord rotation capacity at the limit state of near collapse (NC) is the value of the total chord rotation capacity (elastic plus inelastic part) at ultimate of concrete members under cyclic loading (θ_{um}). The chord rotation capacity corresponding to significant damage (SD) limit state is assumed to be $\frac{3}{4}$ of the ultimate chord rotation $(\theta_{SD} = \frac{3}{4}\theta_{um})$. The chord rotation at yielding (θ_y) corresponds to the limit state of damage limitation (DL).

3.3. Member and Joints Shear Capacity Checks

The diagonal compression induced in the joint by the diagonal strut mechanism should not exceed the compressive strength of concrete. Adequate joint confinement should be provided to limit the maximum diagonal tensile stress of concrete. Also, adequate vertical reinforcement of the column passing through the joint should be provided. The most appropriate retrofit method to upgrade the beam-column joint seismic behavior is using RC jackets for the columns with the reinforcement correctly lapped between the different floors and the stirrups of the jackets continuing inside the beam area [20].

4. RESULTS AND DISCUSSIONS

Effective modal mass ratios and periods of the fundamental mode are illustrated in Table 2. For the initial building eigenvalue analysis, and the effective modal mass ratio of 69.067% indicates the first mode in the Y-direction dominates the response. The first mode period of the building retrofitted by RC jackets and new RC walls decreases while this period for retrofitting by FRP wrapping is the same as the initial building since FRP wrapping does not increase the stiffness considerably.

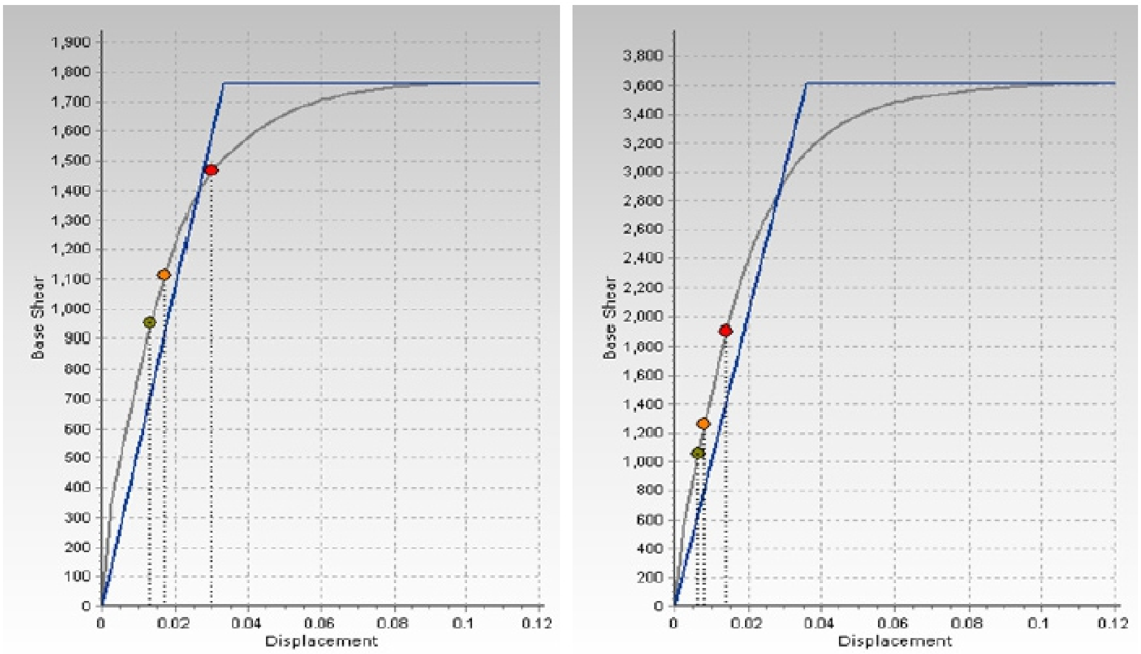
Figure 9 illustrates the capacity curves based on the pushover analysis in Y-direction and the target displacements for the selected Limit States. The target displacements of the building retrofitted by RC jackets and RC walls are less than initial building and retrofitted by FRP wrapping.

The results for retrofitted building by RC walls for the SD limit state indicate a target displacement of 0.75cm and a maximum building capacity of approximately 4900kN at a top displacement of 3.5cm. For retrofitted building by RC jackets, show a target displacement of 0.8cm and a maximum building capacity of about 3600kN at a top displacement of 3.7cm. Also, the results of the retrofitted building by FRP wrapping indicate a target displacement of 1.8cm and a maximum building capacity of 1800kN at a top displacement of 3.5cm. It has been shown that using RC walls and RC jackets may increase the base shear capacity by more than 100%, while there is a substantial decrease in the calculated target displacement of roughly 60%.

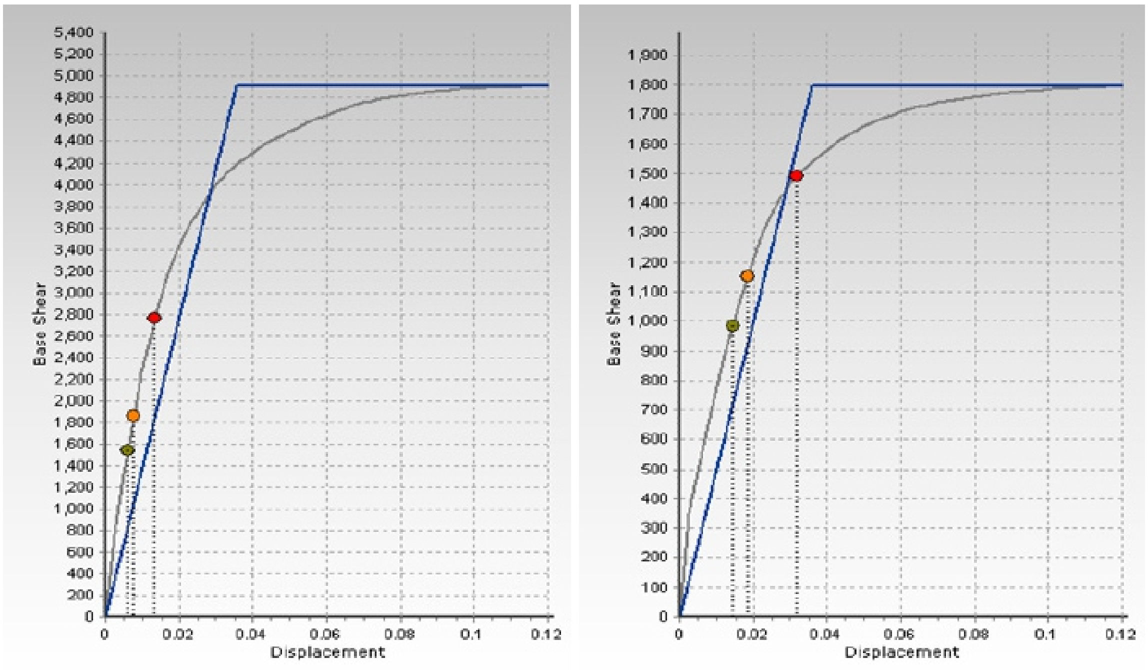
Almost in all the structural members of the initial and strengthened buildings, the chord rotation capacity checks pass the code-based checks criteria. Also, the maximum DCR in shear for the initial building, retrofitted by RC walls, RC jackets, and FRP wrapping, is about 1.51, 0.59, 0.98, and 0.93, respectively. In the dynamic time-history analysis, as it is prescribed in the different codes, the applied loading is always acceleration time-histories at the base of the building. In doing so, a single real accelerogram, which was recorded in the 1999 Chi-Chi earthquake in Taiwan, was applied in the y-direction. It has a peak ground acceleration of 0.35g and a maximum spectral acceleration of approximately 0.65g. As it is shown in Figure 10, the roof displacement time history for the initial building and retrofitted by FRP wrapping are almost the same with a maximum of 1.5cm.

Table 2. Period and effective modal mass ratios of Mode

Mode 1	Period (sec)	Effective Modal Mass Percentages (%)					
		Ux	Uy	Uz	Rx	Ry	Rz
Initial building	0.198	19.306	69.061	0.000	2.621	0.678	0.002
RC Jacketing	0.140	16.371	66.141	0.000	4.184	0.906	0.342
RC Walls	0.128	8.071	72.782	0.000	4.690	0.427	0.000
FRP Wrapping	0.198	19.306	69.061	0.000	2.621	0.678	0.002



(a) (b)



(c) (d)

Figure 9. Capacity curves and the target displacements (a): Initial Building, (b): RC Jacket, (c): RC Walls, and (d): FRP Wrapping

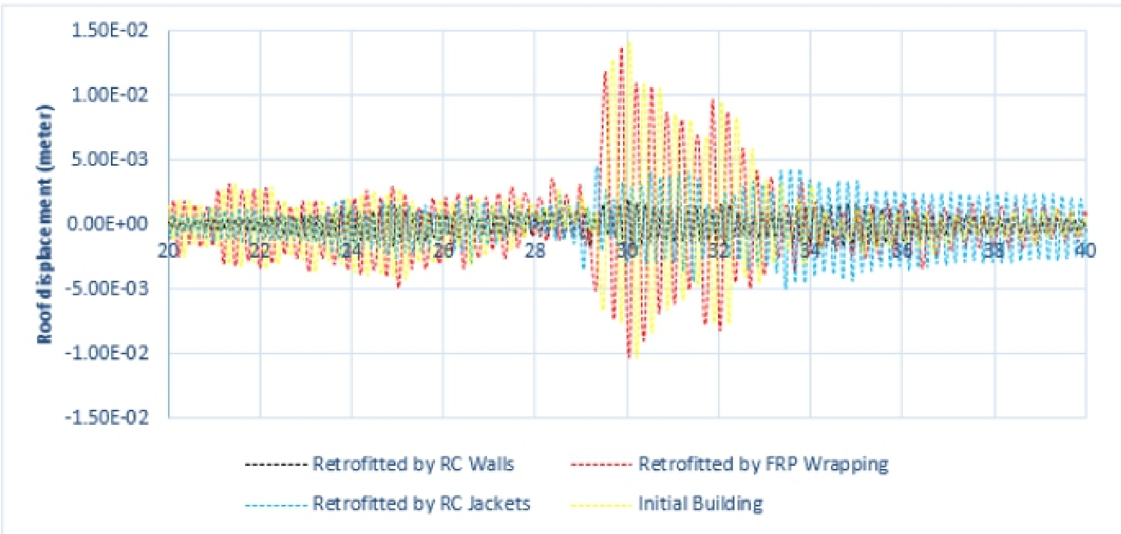


Figure 10. Roof displacement of the Initial and the retrofitted buildings

Although the dynamic behavior is very similar, shear checks are fulfilled much easier, because of the significant increase in shear capacity of the strengthened columns when retrofitting by FRP wrapping. The maximum roof displacement of the building strengthened with RC walls decreases 80%, compared to the initial building, and about 50%, compared to building retrofitted by RC jackets.

Shear walls can undertake most of the total base shear, and the other vertical members have to withstand a small percentage of the total seismic demand or base shear. Consequently, they pass the required checks with less or no intervention. Consequently, it would be better to introduce the elements such as RC walls at the perimeter, in order not to increase the cost for non-structural damage and not to prevent the operation of the building and use of RC jackets or FRP wraps in the columns of the ground floor. An alternative solution would be steel braces mostly for stiffness. The solution applies both FRP wraps and steel braces for better performance, FRPs for strength. The layout of the steel braces or jackets symmetric, in both X and Y directions, is preferred.

5. CONCLUSIONS

A 2-story RC building with a structural deficiency, i.e., lack of stirrups and longitudinal reinforcements, has been analysed, and the most useful seismic retrofitting solutions have been compared and discussed. The structural response of the initial and retrofitted models is analysed and compared. Shear capacity of strengthened members, which are the most critical aspect in RC structures, improved using these techniques. More specifically, the largest DCR in shear for the building has been strengthened by shear walls significantly decreases, concerning initial and retrofitted buildings by RC jackets and FRP wrapping. Eigenvalue analysis of the buildings retrofitted by RC jackets and RC walls indicates a significant increase in the stiffness of the building, i.e., a considerable decrease of more than 30% in the fundamental period concerning the initial building. The results of the pushover analysis of the buildings retrofitted by RC jackets and RC walls indicate a significant increase in the capacity of more than 100%. Furthermore, as a result of increasing the building stiffness, there is a considerable decrease in the calculated target displacement of almost 60%. The results from the Eigenvalue analysis, capacity curve, and target displacements of the building retrofitted by FRP wrapping are almost identical to the results of the initial building, although the retrofitted buildings show larger ductility.

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The Temperature Field in Mass Concrete with Different Placing Temperatures

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ABSTRACT

Hydration heat of concrete mix has an important role in the process of temperature increase in mass concrete at an early age. Thermal stress caused by the temperature difference between the core and the surface of mass concrete is the main reason in making thermal cracks if the stress is larger than the tensile strength of concrete. The aim of this study is to investigate the effect of placing temperature on temperature distribution and thermal stresses of mass concrete. A proportion of concrete mix of interest is used for the thermal analysis of a mass concrete sample sized 8×6×3 m. The finite element Midas Civil program is used to conduct the three-dimensional thermal simulation. Four typical scenarios of placing temperature in the range of (15-30)°C of the concrete mix, which is commonly used in actual construction condition, are presented. The analysis results of temperature distribution and thermal stress indicate that the value of 30°C of placing temperature according to the selected proportion of concrete mix may cause thermal crack in the mass concrete. The study gives a useful way for practical construction application to avoid the risk of thermal crack in mass concrete at an early age.

Keywords Maximum Temperature, Temperature Difference, Mass Concrete, Placing Temperature, Thermal Crack

1.INTRODUCTION

Mass concrete are normally used for hydraulic structures, bridge, foundation of high-rise buildings, and etc. One of the significant factors affecting the stress-strain state of the concrete mass during construction and operational process is temperature effect due to hydration heat of cement [1-3].

The temperature regime in mass concrete structures is affected by many factors, such as air temperature, wind speed, water temperature, intensity of solar radiation and shading effect, foundation temperature, and especially amount of hydration heat which is caused by the cement type and its content [4-6].

In addition, the temperature distribution in the mass concrete is also influenced by other factors, such as schedule of placement, aggregate size used in mass concrete, initial temperature of concrete mix, curing condition, etc. As a result, high temperature gradient occurring during the construction may cause significant tensile stresses and lead to thermal cracks [7-9].

The temperature difference between the inner zone and the outer surface of the mass concrete is the reason causing the formation of thermal stress. If the tensile stress is larger than the tensile strength of the mass concrete, thermal cracks form on the surface of the concrete structure, especially at the early age. In order to avoid the formation of thermal cracks, a general condition is that the temperature gradient ΔT should not exceed 20°C [10].

On other aspect, to minimize the temperature difference between the inner zone and the outer surface of mass concrete causing thermal cracks, past researches indicated several curing methods by using different types of insulation material together with its thickness, such as polystyrene [11], sand layers [12]. In addition, cooling pipe system is quite a perfect solution to reduce hydration heat in the core of mass concrete [13].

In the present study, effect of the placing temperatures causing different temperature gradients between inner and outer zones of mass concrete is investigated. The temperature profile versus time and its maximum value together with thermal stresses in mass concrete corresponding to different scenarios of placing temperature are simulated by using the finite element Midas Civil program. From the analysis results, it is proposed an appropriate value of placing temperature to control the risk of thermal cracks in mass concrete at early and best suit the actual construction conditions.

2. MATERIALS AND METHODS

2.1. Object of Research

A 3D model of the concrete mass body sized 8×6×3 m and laid on the foundation sized 16×12×4 m is modelled. To increase the speed of the simulation, a half of the symmetry model is used to simulate the scenarios of placing temperature as shown in Figure 1. The mesh of the model is divided into 1920 elements and 2509 nodes. It is noted that the element size of the model is carefully selected and fine enough based to get acceptable accuracy results on a parametric study.

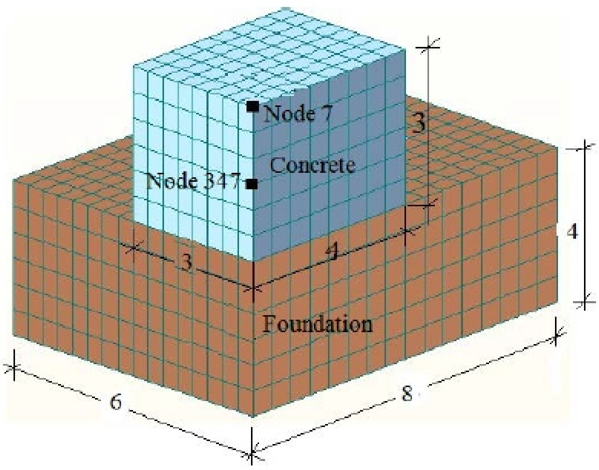


Figure 1. 3-D thermal analysis model for concrete mass, unit m

For the definition of contact at the interface of mass concrete and foundation, a defaulted contact option available in the FE program is used to simulate perfectly conductance between two solid objects through this contact. The temperature difference between the node at center and node at the surface of the concrete mass is affected by the convection coefficient on concrete-air interface. The convection coefficient can be adopted by the proposed empirical equation (1) [14,15]:

$$h_c = \begin{cases} 5.6 + 3.95v, & v \le 5m/s \\ 7.6v^{0.78}, & v \ge 5m/s \end{cases} \quad (1)$$

where: v - the wind speed, m/s.

In this research, a constant value of convection coefficient on the formwork-concrete surface of mass concrete and the average air temperature are assumed to be 12 kcal/m2h°C and 30°C, respectively. To investigate the effects of placing temperature on the temperature regime in mass concrete, four scenarios of concrete placing temperature, corresponding to 15°C, 20°C, 25°C, and 30°C, are proposed. It is seen that these placing temperatures above spread in a range of placing temperature that is commonly used in actual construction condition. The composition of concrete mix of interest used to describe the development of temperature versus time of the mass concrete are presented in Table 1.

Hydration heat is generated by the products of chemical reactions during hydration of Portland cement with water. Hydration heat is very important factors because it is used as source of heat in concrete mass. The hydration power of concrete mix is shown in Figure 2 [16]. And, the thermal characteristics of concrete used for the analysis are shown in Table 2.

Table 1. Mix proportion of concrete [16]

Material, kg/m^3					
Cement	GGBF Slag	Fly Ash	Water	Aggregate.	
				Fine	Course
202	202	0	202	645	990

Table 2. Important parameters of concrete and foundation

Important parameters	Concrete	Foundation
Thermal conductivity coefficient, k [W/(m.°C)]	2.9	2.1
Specific heat, C [kJ/(kg.°C)]	1.12	0.85
Specific weight, ρ [kg/m^3]	2400	2600
Coefficient of thermal expansion, [1/°C]	1×10^{-5}	1×10^{-5}
Poisson's ratio	0.2	0.3
Elastic modulus, N/m^2	2.5×10^{10}	1.8×10^{10}

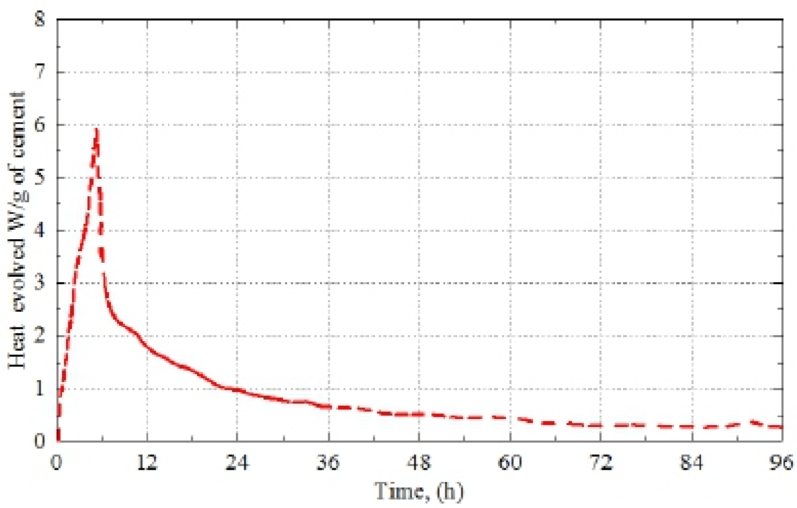


Figure 2. Hydration power of concrete mix

2.2. Finite Element Method to Solve the Thermal Model

The solution of the thermal problem is based on the differential equation of the heat conduction theory [17-20]:

$$k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+q_v=\rho c\frac{\partial T}{\partial t}, \qquad (2)$$

where: k - thermal conductivity of materials, W/m°C;
c - specific heat, kJ/(kg.°C);
q_v - the rate of thermal energy generated per unit volume, W/m^3;
ρ - density, kg/m^3;
t - age of concrete at the time, day.

To solve equation (2) it is necessary to apply the boundary condition as given by equation (3) [21, 22].

$$k\left(\frac{\partial T}{\partial x}n_x+\frac{\partial T}{\partial y}n_y+\frac{\partial T}{\partial z}n_z\right)+q_v=0 \qquad (3)$$

where: n - vector normal to the direction of heat transfer.

Finite element method to solve the problem of heat transfer is expressed by the equations as follows [23, 24]:

$$[K]\{T\}+[C]\left\{\frac{\partial T}{\partial t}\right\}=[Q], \qquad (4)$$

Time interval for the steps Δt can be described as follows:

$$\left\{\frac{\partial T}{\partial t}\right\}=\frac{1}{\Delta t}\left[\{T(t_n)-T(t_{n-1})\}\right], \qquad (5)$$

Then, the equation (4) can be rewritten as follows:

$$[K]\{T\}+\frac{[C]}{\Delta t}[\{T(t_n)-T(t_{n-1})\}]=[Q], \qquad (6)$$

where: [K] - the global stiffness matrix at time tn;
[C] - capacity matrix;
[Q] - thermal load vector;
Δt =Δtn - Δtn-1 - steps of computation time.

Solving the equation (6) allows to obtain temperature fields in concrete mass at different times. The flow chart of the methodology of finite element analysis for heat transfer problem in mass concrete is given in Figure 3.

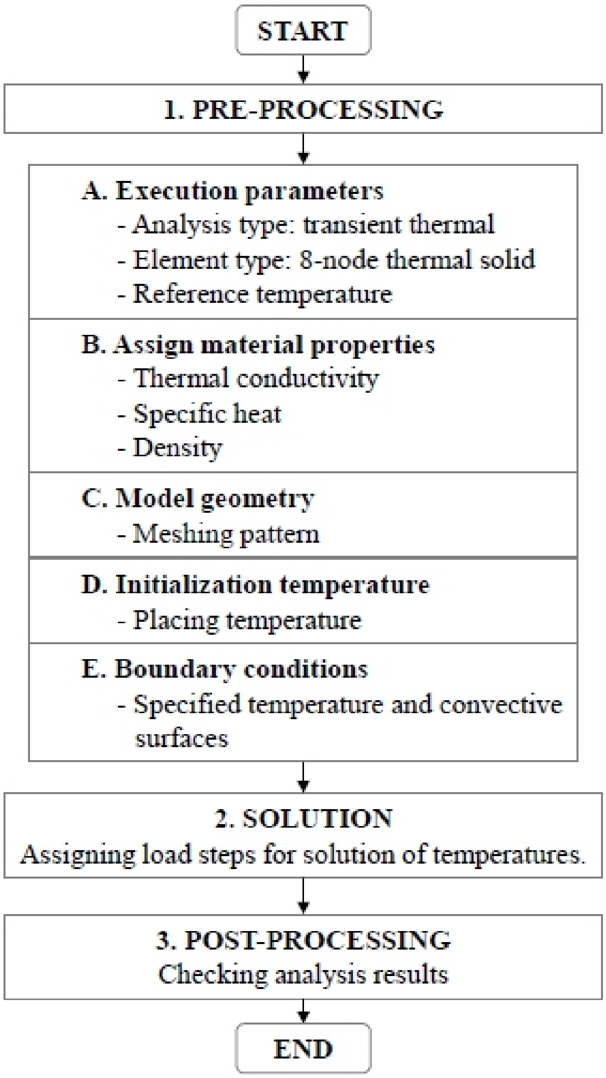


Figure 3. The flowchart of the computational temperature fields by FEM

Similarly, the general equilibrium equations of thermal stress depending on space and time, which is calculated in the finite element method [25].

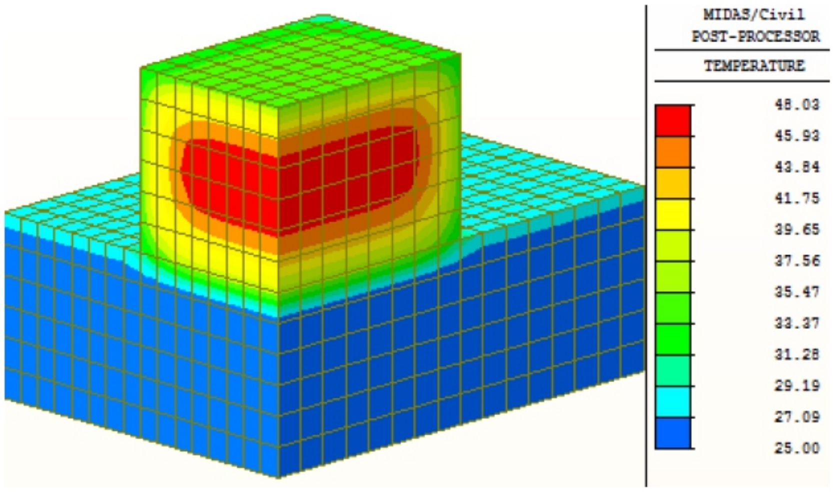
$$[K]\{\Delta\delta\} = \{\Delta Q\}^L + \{\Delta Q\}^C + \{\Delta Q\}^T + \{\Delta Q\}^g \, , \quad (7)$$

where: $\{\Delta\delta\}$ - displacement increment vector of a time interval Δt;

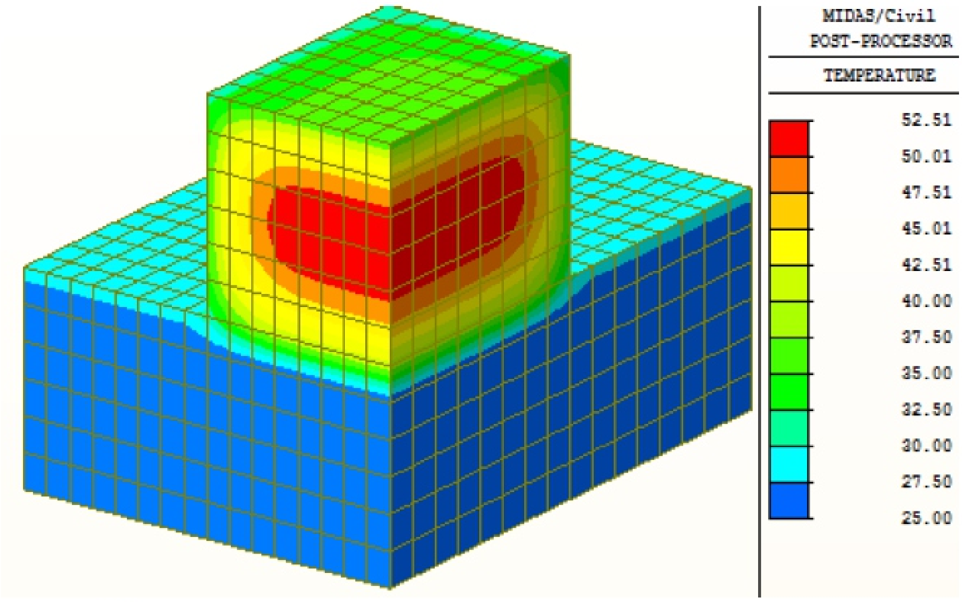
$\{\Delta Q\}L$, $\{\Delta Q\}C$, $\{\Delta Q\}T$ and $\{\Delta Q\}g$ - load increment vectors of external load, creep, temperature and autogenously volume deformation, respectively.

3. RESULTS

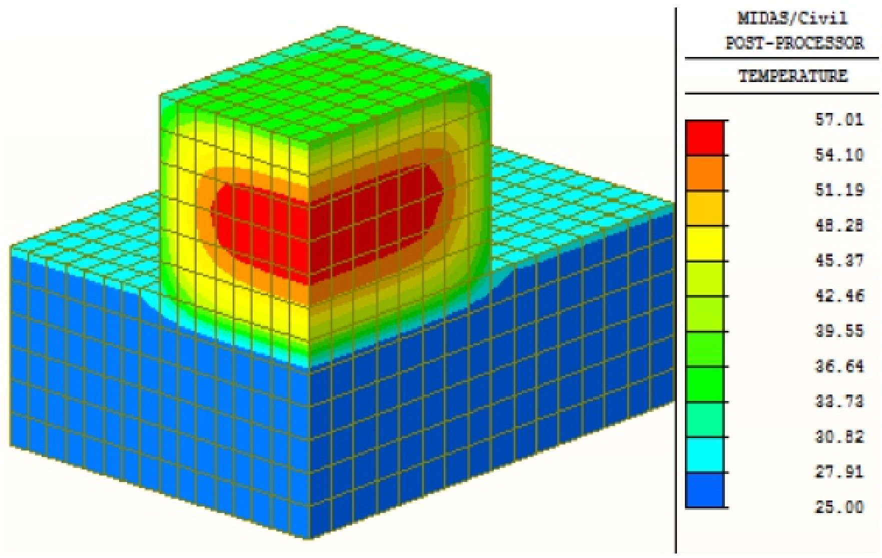
The results of the conducted numerical model are shown in Figures 4–7. The adopted temperature distributions in mass concrete with the different cases of placing temperature are described in Figure 4.



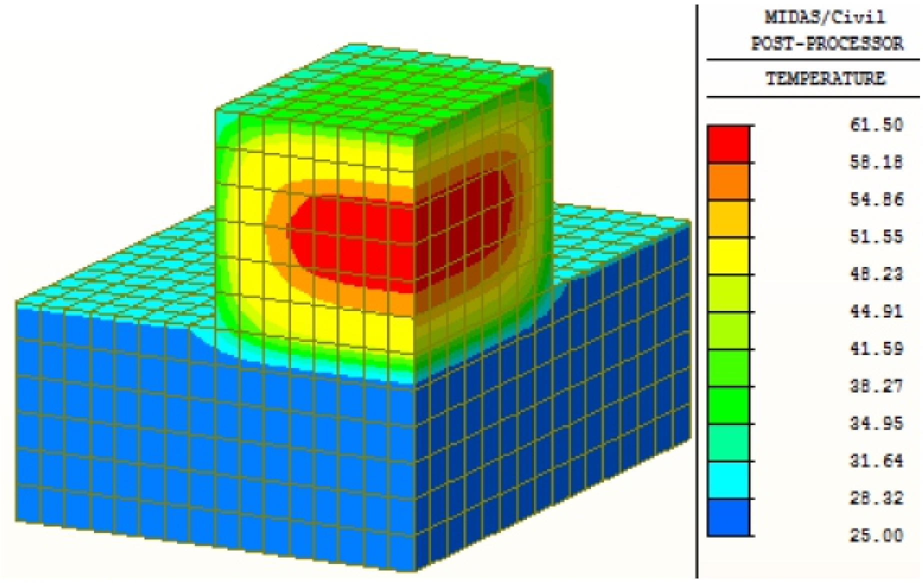
(a) - T_{pl} = 15°C



(b) - T_{pl} = 20°C



(c) - T_{pl} = 25°C



(d) - T_{pl} = 30°C

Figure 4. Temperature distributions in mass concrete with different cases of placing temperature

Placing temperature has an important effect on the hydration process of concrete mass an early age. The higher placing temperature of the concrete mix, the higher maximum temperature at the core of the concrete block is achieved. The effects of placing temperature on the hardening concrete temperatures are shown in Figure 5. As can be clearly seen, the maximum temperature at the core of the mass concrete is lower when the placing temperature of concrete varies from 30°C to 15°C. The temperature in the core of the concrete block increases fast and gets the peak values at 2-3 days after placement, then the temperature at this location slowly reduces by time. The maximum temperature at the center of the concrete mass, corresponding to the analysis cases Tpl of 30°C, 25°C, 20°C, and 15°C are 61.61°C, 57.0°C, 52.51°C, and 48.01°C, respectively.

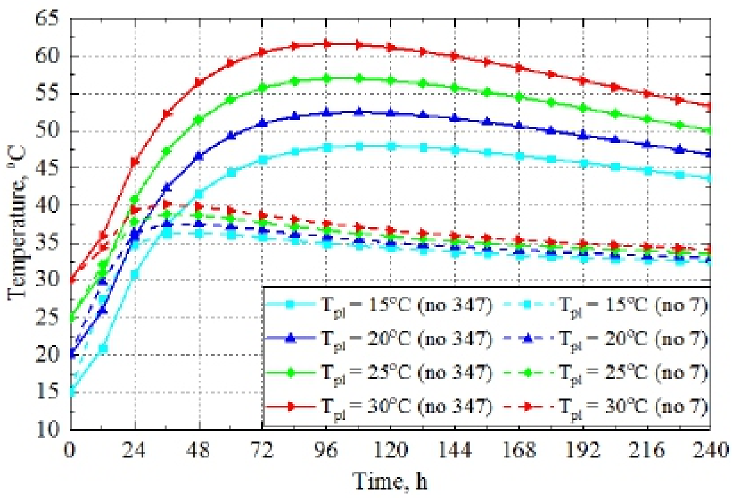


Figure 5. Temperature development at the centre (node 347) and at the surface (node 7) of the concrete mass

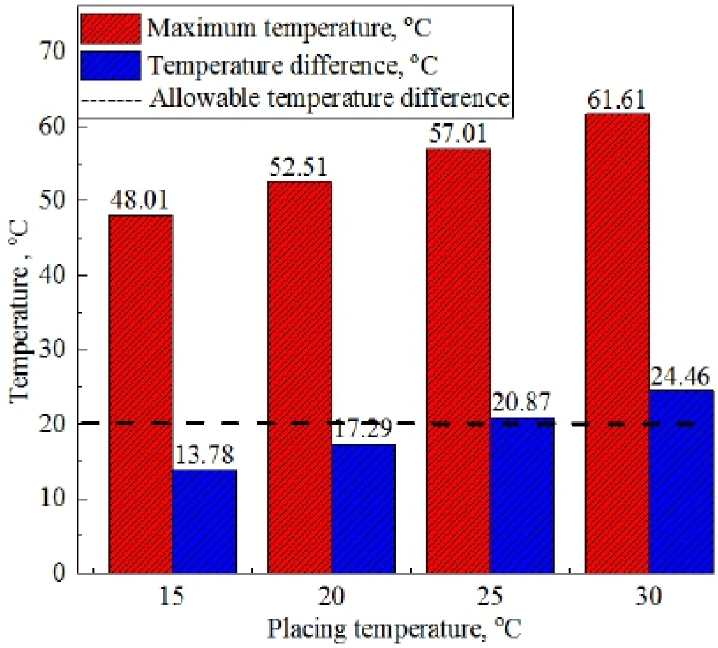


Figure 6. Relation between placing temperature, maximum temperature, and temperature drop in the mass concrete

Figure 6 shows that the maximum temperature and the temperature drop in the concrete block with four cases of placing temperature of concrete mix obtained to the linear lines. So, when increasing 1°C of placing temperature mixture of concrete, the maximum temperature and temperature difference in the concrete block also approximately increased 1°C.

It is noted that when the placing temperature of the concrete mix exceeds 25°C, the temperature difference between the center and the surface of the concrete block exceeds 20°C. This value is particularly important since many specifications showed that the maximum temperature difference should not exceed the limitation of (15-20)°C to avoid the thermal cracks.

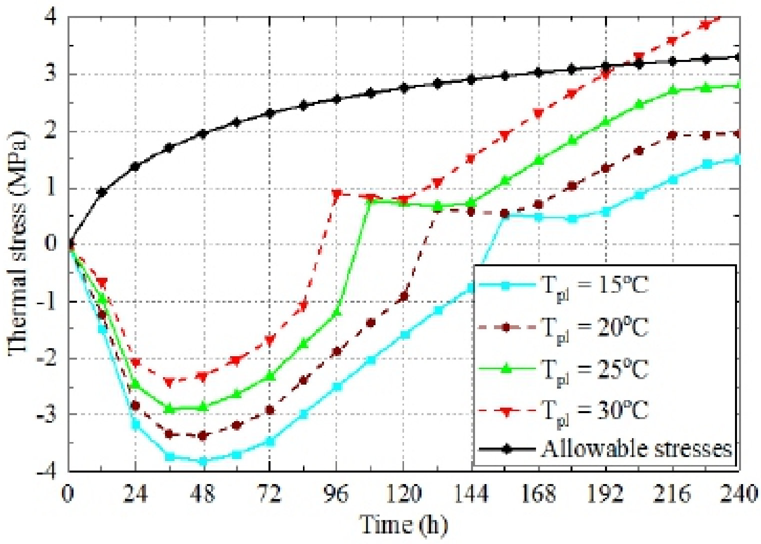


Figure 7. Changes in the thermal stress at node 7 (at the surface of concrete mass)

The surface of the concrete block is the area at which mayoccur the thermal cracks due to the temperature difference between the center and concrete surface. For more in details, the thermal stress analysis is conducted, the obtained values are presented for the node of interest (node 7) corresponding to different cases of placing temperature as shown in Figure 7.

Figure 7 indicates that the tensile stress on the surface of the concrete block will exceed the allowable tensile stress, corresponding to the case tpl = 30oC. Thus, thermal cracks may form on the surface of the concrete mass in this case. It is recommended to consider the appropriate options to control the exceeded thermal tensile stress, such as reduce the cement content by replacing mineral additives, cooling the mixture before pouring concrete, using cooling pipe and insulation surface.

4. CONCLUSIONS

Based on the selected mix proportion of concrete, the analysis results of the study give some conclusions as follow:

1. Based on the selected mix proportion of concrete, the higher placing temperature causes higher maximum temperature in the center of the concrete block.
2. When the placing temperature is higher than 25oC, the maximum temperature difference between the center and the surface of concrete block is higher than the limitation of temperature difference which commonly varies in the range of 15-20°C to avoid the thermal cracks.
3. The analysis case of tpl = 30oC, the high placing temperature causes a tensile stress that exceeds the tensile strength of the concrete and may lead the cracks on the surfaces of the concrete block. It is possible to select one or combined appropriate options to control the thermal stress in the mass concrete block.

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