Evaluation of Concrete Core testing

Project Advisor: Maj.Dr.Rizwan

Syndicate members:

NS-3893 M. Tayyab Amin (183089)

NS-3913 Fasih-ur-Rehman (197477)

NS-3910 Arslan Tahir Bajwa (190449)

NS-3904 Hamza Arif (196414)

ASC-2572 Muhammad Ukasha (201341)

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ABSTRACT:

Concrete, being the most widely used material in modern structures worldwide. It performs a very significant role in giving strength to structure when combined with reinforcement. However, poor workmanship, workability & material may cause adverse effect to the concrete & strength may not pertain to the design specifications. Therefore, forensic investigation is carried out to quantify the deterioration in concrete for which Non-Destructive Testing (NDT) in combination with core extraction may be carried out. For the aforementioned reason, cores are extracted from the suspected members of the structure without damaging the reinforcement & results are compared with their respective design strength obtained from cylinders casted at the time of pouring of concrete. During extraction & testing process of the cores, it might not depict the actual strength of concrete due to the stresses developed in concrete while the core is extracted, core's diameter, length to diameter proportion, direction of core extraction etc. An objective of this research is to establish a model to correlate the actual strength of cores with cylinder casted at 28days & cores extracted from the respective specimens with variation in diameter, aggregate size & strength of concrete. But there is an unreliability factor as different Codes have different guideline & provisions for the different correction factors. We'll take a deep look into different codes provisions.

INTRODUCTION:

Concrete compressive strength is quite important to all concrete structures subjected to different forces/loads. In fact, it offers the good measure of additional significant aspect of concrete. To determine concrete compressive strength, standard concrete cylinders giving the required strength are prepared & examined during construction. These test specimens are then tested as per specifications. But determining the concrete strength in an existing structure is not easy, as it depends upon a number of factors including curing, compaction & materials used. Therefore, there always come a question whether concrete test specimens represent the real concrete's strength in the arrangement. This query turns out to be more significant when the strength of typical concrete cylinders falls short of specified. In such a case, there are two possibilities: whether the concrete's strength in the structure is small or the test samples don't represent the concrete in an organization. To solve this issue, we drill cores from suspected members of the building & testing them. Sometimes, it is not possible to test regular test samples at a later stage & this is obligatory to find concrete's strength in the existing arrangement for durability & safety when subjected to higher stress. In such conditions, the core test for concrete is helpful for determining properties of concrete in the structure. Commonly actual concrete strength is found out by drilling concrete cores & testing them. Though the method is a bit expensive, it gives reliable results as cores are subjected to compression tests until destruction. The strength of core is influenced by the several factors like slenderness ratio, moisture, steel bar & their spacing etc. Therefore, core test outcomes should be understood to obtain actual data.

There are some other conditions where taking cores becomes essential. For instance, when subjecting an existing structure to heavier loads or the structure is to be used for some other purpose, thus the load bearing capacity needs to be checked or to verify that the concrete isn't damaged by fire, overloading or due to some chemical reaction.

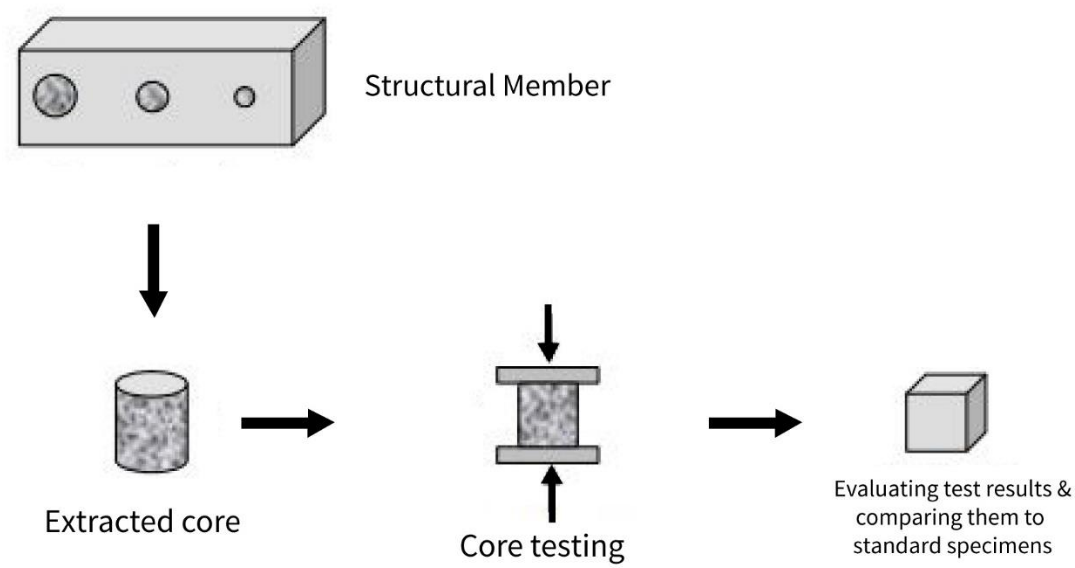


Fig. 1 Core testing process

LITERATURE REVIEW:

To find the in-situ core strength, code gives dissimilar consequences depending on corresponding factors employed. The general approach to find core strength is to divide eventual load by cross-sectional area (using average diameter of core). But problem lies to translate core strength to corresponding to cylinder strength. As mentioned earlier, the strength of core is influenced by the lot of factors like moisture level, slenderness ratio, steel bars etc. therefore care must be taken to interpret results. Table shows the factors used in different codes.

Factors involved in interpretation of core results by different codes

Sr.No	Code/standard	Factors Considered					
		Aspect ratio	Diameter	Reinforcing	Moisture	Damage	Direction
1	Egyptian Code (2008)	✓		✓			✓
2	American Concrete Institute ACI(2012)	✓	✓		✓	✓	
3	ASTM C 42 (2013)	✓					
4	Concrete Society	✓		✓		✓	✓

Table1. Different Codes Guidelines

Current Egyptian Code (2008)

According to Egyptian Code, the in-situ strength of concrete can be premeditated using equation:

$F_{cu} = (F_{l/d})* (F_{reinf})*f_{core}$

Where

$(F_{l/d})$ = factor for accommodating slenderness ratio (l/d)

(F_{reinf}) = shows presence of reinforcement

In case, there is no reinforcement, F_{reinf} =1

To find these factors,

$F_{l/d} = (D)/(1.5+1/\lambda)$

$F_{reinf} = 1 + 1.5\ (\Phi_r * d)/(\Phi_c * l)$

Where D = 2.5 for drilled cores in horizontal direction

While D = 2.3 for cores drilled in vertical direction

λ = Slenderness ratio(l/d)

Φ_r = Dia of steel bar

Φ_c = Dia of core

l = core length

d = distance between the axis of bar & core end

ACI CODE (2012):

Since 2003, significant changes were made to evaluate concrete core strength results. The factor measured are aspect ratio(l/d), diameter, dampness & core damage due to drilling. As per the ACI code, the in-situ strength is computed as:

$$f_c = F_{l/d} \cdot F_{\text{dia}} \cdot F_{\text{mc}} \cdot F_D \cdot f_{\text{core}}$$

Where $F_{l/d}$, F_{dia}, F_{mc}, F_D, f_{core} are concrete strength correction factors due to aspect ratio(l/d), diameter of core, Dampness quantity in core & damage during piercing correspondingly.

fc = Concrete in-situ strength

Correction Factors for strength in accordance with ACI (2012)

List	Factors	Mean values
(1)[b]	$F_{l/d}$: l/d ratio	
	As-received	$1-\{0.130-\alpha f_{core}\}\left(2-\frac{l}{d}\right)^2$
	Soaked 48 h	$1-\{0.117-\alpha f_{core}\}\left(2-\frac{l}{d}\right)^2$
	Air dried[a]	$1-\{0.144-\alpha f_{core}\}\left(2-\frac{l}{d}\right)^2$
(2)	F_{dia}: core diameter	
	50 mm	1.06
	100 mm	1.00
	150 mm	0.98
(3)	F_{mc}: core moisture content	
	As-received	1.00
	Soaked 48 h	1.09
	Air dried[a]	0.96
(4)	F_D: damage due to drilling	1.06

[a] Standard treatment specified in ASTM C 42/C 42M.
[b] Constant α equals $4.3(10^{-4})$ 1/MPa for f_{core} in MPa.

Table 2.Factors considered in ACI (2012)

Concrete Society (CS):

Concrete society helps to estimate concrete potential strength instead of in-situ strength.

Using the following equation, we can find out concrete potential strength:

$$f_{pot} = (F_{l/d}) \cdot (F_{Reinf.}) f_{core}$$

Where f_{pot} = Potential Concrete strength

$F_{l/d}$ & $F_{Reinf.}$ are factors of correction for aspect proportion & presence of steel.

$F_{l/d} = (D) / (1.5 + 1/\lambda)$

$F_{Reinf} = 1 + 1.5(\Phi_r * d)/(\Phi_c * l)$

Guidelines for testing:

Core Marking:

After extracting cores, mark the following details for later use:

- Coring depth
- Location reference (from where core is taken)
- Direction of drilling
- Core dia

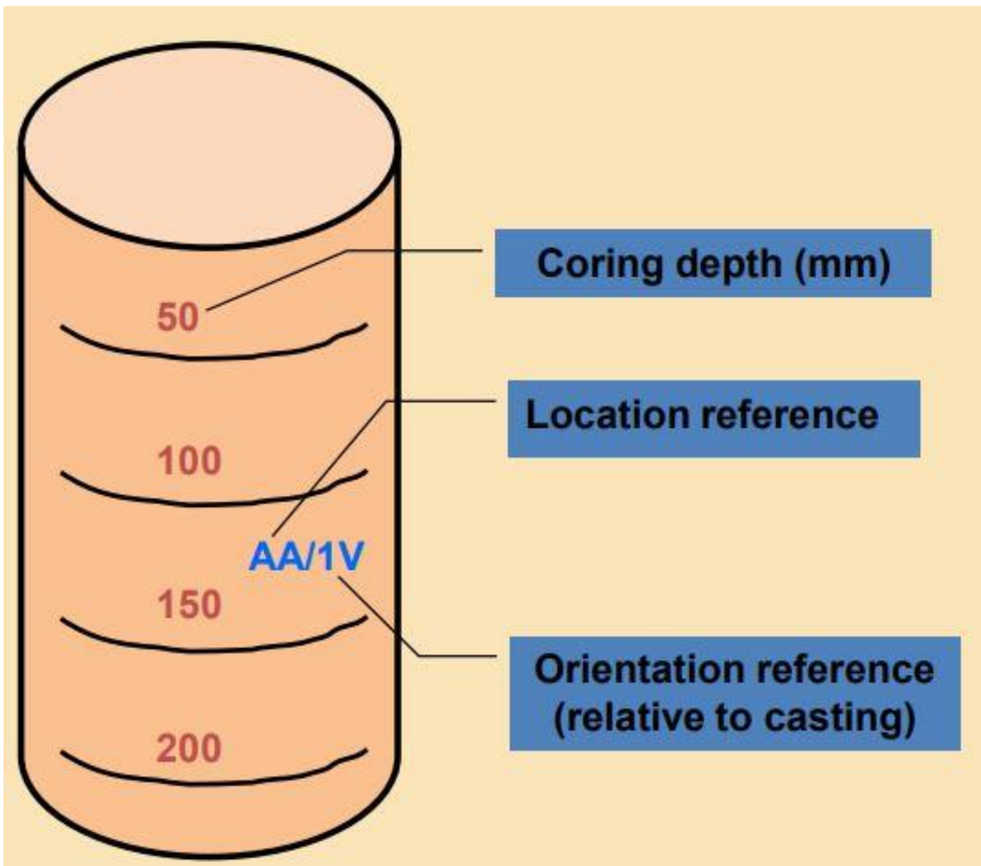


Fig 2. Marking cores

Trimming & capping:

If the ends of core are not smooth & parallel, the applied axial load wouldn't be uniformly distributed & will alter the test results. For obtaining cores with smooth & parallel ends, trim them with diamond saw. According to ASTM C617, cores should be capped using molten sulphur mortar. The thickness of capping should be kept as minimum as possible. i.e. 10mm. After capping, cores must be cured for at least 2 hours before testing.

If the ends are perfectly smooth, then there is no need of capping.

It is important to note that the cylinder axis doesn't vary more than 0.5^{o} from vertical axis.

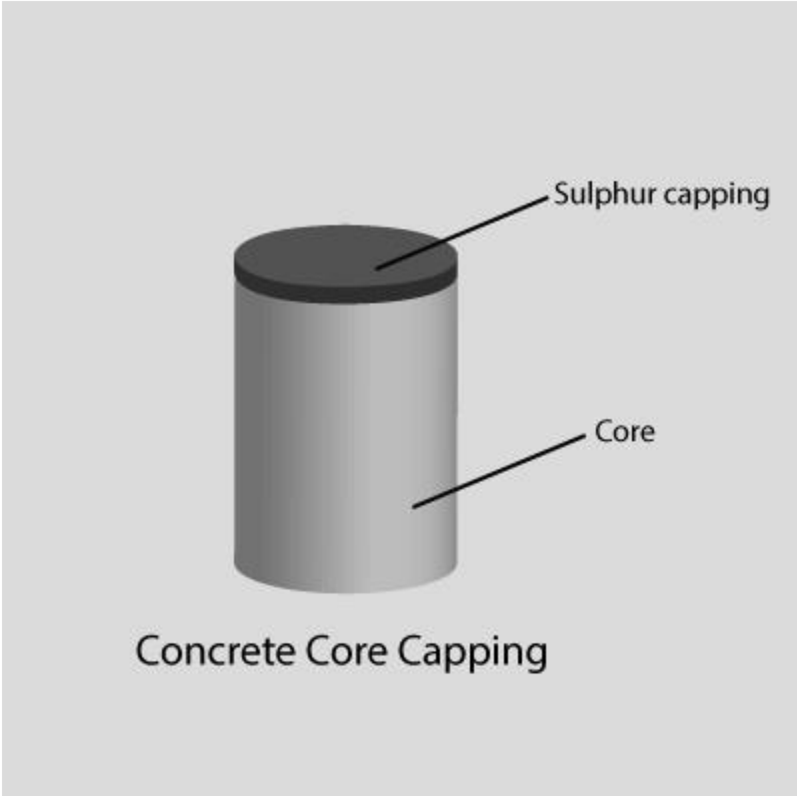


Fig 3. Concrete core capping

Testing concrete cores:

Core testing results are considered satisfactory when the core's average compressive strength is equal to 85% of a stated strength & the strength is not lesser than 7% for each and every core.

Drilling Cores:

Although core specimens from the structure are the representative of concrete strength in the structure, care should be taken of various factors that affect core strength. Taking out a core full of voids, due to poor compactions, will decrease the strength. Besides the drilling operation, the location of specimens in the structure affect the strength. Cores taken from the upper top of concrete surface have low strength as compared to those taken from bottom surface due to bleeding.

Cores should be taken from a structure where concrete has got sufficient strength. Generally concrete needs to be at least 14 days old for specimens to be removed. Preferably cores should be taken after 28 days of placing the concrete.

Cores are generally taken employing rotary cutting device equipped with diamond bits. Core drilling machines must be supported firmly against the concrete for preventing their relative movement that results in slanted cores. During drilling process, continuous water supply is needed for lubrication.

Fig 4. Core drilling machines

Core Measurements:

Before concrete core testing, measure the length & diameter of core including capping (if done) & determine the l/d ratio.

Fig 5. Measuring core dimensions

Core Density:

Determine the core density without capping by weighing it & dividing by its volume.

Core Testing:

Prior to testing, place the cores in water at room temperature (25^{o}) for 48 hrs. Place the core carefully inside the testing machine & start applying the load at the persistent rate of 0.25±0.05 Mega Pascal per second or (357±psi per second). During this process carefully observe any failure & appearance of cracks in concrete. Find the compressive strength of core by way of dividing the Eventual load by the core’s cross section area (measured using core’s average diameter).

Fig 6. Concrete core testing

Value of **D** depends upon the direction of drilling. According to CS, D equals 3.2 for horizontally drilled cores while 3 for upright drilled cores in the direction of casting.

Generally concrete potential strength is 1.5 time the core strength provided aspect ratio (l/d) =2, cores are drilled vertically and are free of steel.

Where to take the cores?

The preference on this is based on the questions & queries that the engineers want an answer to. There are many valid questions. The two most popular queries are: Does the concrete match the requirements needed? What is the total compressive structural strength of concrete? Concrete cores should be taken from various locations from the entire structure to answer these questions. But there are limitations, concrete cores taken from any member's upper section or concrete lift are most often weakest and therefore cannot be representative.

There can be another question: If strength of the especially highly stressed portion of the system is appropriate or not enough? In such situations, the positions for the core extractions should be carefully selected so that capacity to bear the structure load should not be decreased by the removal of the concrete from the section where it is required the most. Adequate locations for core extraction can be identified only by engineer with the proper knowledge about structural action.

To answer this question, is the actual loading system adequate in strength? Also, an engineer will know where to check even when the strength of the loading device is not appropriate. We can say, as if a structure isn’t suitable for the capacity of original scheme, it is capable of bearing more modest charge. In such a case, the owner might be able to resolve the matter by compensating for the work completed with a lower fee than decided to in the contract. Such requirements can be agreed by the contractor, rather than by wholesale removing of concrete previously placed and renovation of the structure

The concealable delay in the project due to removal and replacement can be avoided which is convenience for the owner. It may be distinguished well that the predetermined requirement for the lots of concrete expense with lower strength suggested but agreed by an engineer is probable for having the beneficial impact on the efforts of servicer in terms of concrete quality.

Length Diameter ratio:

A standard cylinder's length diameter ratio (L / D) is 2 is the simple answer to the question, but more needs to be said as it is essential and worth giving the reasons as a standard for choosing L / D=2. It is also important to discuss the criteria for cores where the choice of value of length to diameter ratio stays in hand of those who carry out the test unlike the test cylinder in which a mold regualte the value of length to diameter ratio.

Tests that guided to the option of L / D=2 were carried out long ago. Gonnerman said in 1925 that 6 by 12 in. cylinder is now commonly used in compression testing.   IN 1957 Murdock & Keslar put forward the strong evidences for choosing L / D=2. They demonstrate the contrast for L / D values close to 2 in the calculated compressive strength of the cylinder was small and become more prominent for values between 1.0 to 1.6. Mode of failure is the reason for this situation: The testing machine platens are considerably more significant is the squat specimen than it is in the slenderer specimen. The value of the correction factor to equalize the test outcomes with a value of the typical specimen's strength is much bigger at lesser value of L / D and the need for correction factors should be reduced

When standard test cylinders have L/D=2 value only then the use of core with that value is appropriate. In countries where cubes are used the core should preferably have L/D=1; European Standard BS EN 125041:2000 recommends this method which serves equally to the countries which use cylinders and those which use cubes. UK uses cubes, and British standard 6089:1981 specifies that before caping, the value of L / D should be between 0.95 & 1.3.

Though it hasn't been clearly revealed for being the case, the judgement in this regard is that the cylinder (core/molded) having the worth of L/D equal to one (L/D=1) has nearly the equivalent strength as of the cube in which the size of edge is equivalent to cylinder with respect to its diameter.

L/D correction factors

For conversion of a strength found on the trial sample having the value of length to diameter ratio to strength which will be acquired by means of the test on a sample having Length to diameter ratio equal to two (L/D=2) the "correction factor" employed is well acknowledged however the actual query is that to which extent these correction factors are good?

It has been said by Murdock & Keslar that correction factor is basically the functions of an extent of concrete's strength. The concrete which is sturdier, is less affected by the value of length to diameter ratio in contrast with a concrete having less strength. Rendering to "ASTM C 42-99", concrete having strength more than seventy Mega Pascal (70Mpa=10 thousand psi) is not as much of influenced by value of length to diameter ratio. Correction factor provided in the "ASTM C 42" & several other criterions are present in the definite distinctive values/mean values. For instance, as provided in "ASTM C 42", employing a particular set of correction factors can make a big deal with outcomes of the test performed on the core having the minute value of length to diameter ratio (L/D) pierced from the concrete structure having lower strength and thus far it is for this kind of concrete that an estimation of strength can be significant on the whole.

As a consequence, the indecision about the under observation concrete's strength is up surged by the utilization of the correction factor, and it can be perceived through the opinions, as related to the state in which the complete core has length to diameter ratio equal to 2 (L/D=2). As a result, if conceivable, all tests must be carried on core having length to diameter ratio of 2.

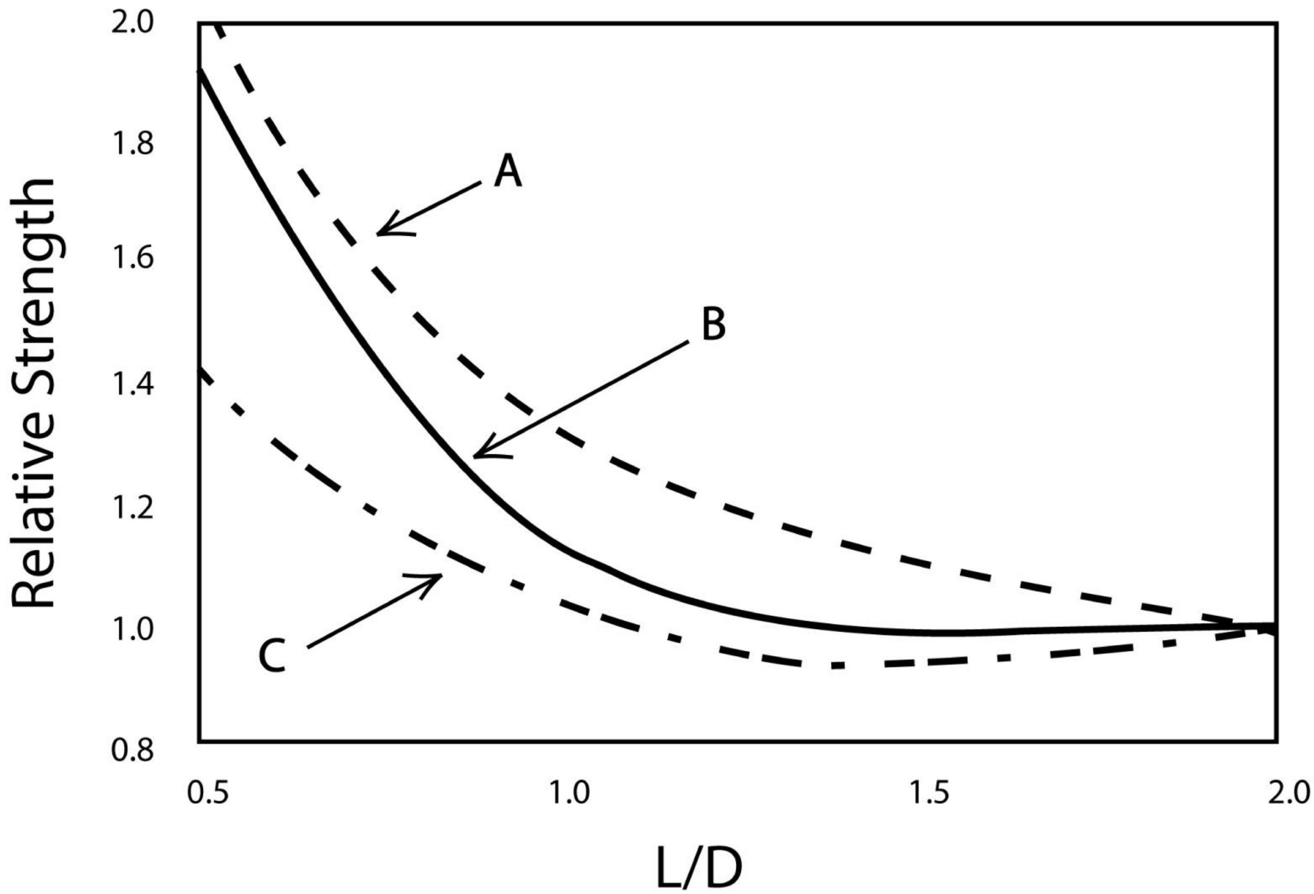
A very interesting fact that should be taken into consideration about "ASTM C 42" is that the very identical standard of it provides a very dissimilar set of correction factor with its variable editions. Centered on the studies of MacGregor & Barlett, all of these are given in table. As it is already specified that a "true" value of these correction factors can be the function of the humid state of the core on testing time. Each and everything is in conflict with the utilization of the cores having varying length to length to diameter ratio values combined with dependence on correction factor.

Derived from earlier tests, one new statement in the study by Murdock & Keslar "the data on the specimens whose L/D was less than 0.5 were erratic." These conditions are apparent in figure. An additional test specified that the "correction factor" for length to diameter ratio of 0.5 was 13.98 for 21 MegaPascal (3 thousand psi) concrete and 1.68 for 31Mpa (4500 psi) concrete. Murdock and Keslar quoted value as high as 2.09. It is not supervising that's why BS It is stated by "6089:1981": "Little reliance can be placed on results obtained on cores having length/diameter ratio of less than 0.5."

From the above confab, my inference is that the cores having length to diameter ratio of smaller than one should not be employed, and thus far I have perceived the usage of cores having length to diameter ratio of 0.6, six inch/150 mm diameter cores were taken out from four inch/100 mm or thinner slabs. Tanking cores with smaller diameter or by sub-coring we can avoid the testing the cores with less value of L/D. The least width of a core to be examined in comparison still remains the issue.

Cores that are too long has no problem as they are able to be cut with the aim of getting the value of the proportion of the covered length to diameter in between 1.9-2.1 that is defined and chosen by "ASTM C 42". Correction factors merely need to be applied when the L/D is less than 1.8.

A number of correction factors for length to diameter ratio are simply applied to the concrete having normal weight even this isn't always mentioned clearly. As stated by "ASTM C 42-99" these factors can similarly be applied on to the concrete having light weight with the density ranging from 100-120lb/ft^3(1600 & 1999 kg/m^3). For the concretes of lower density there are still some uncertainties about correction factors.



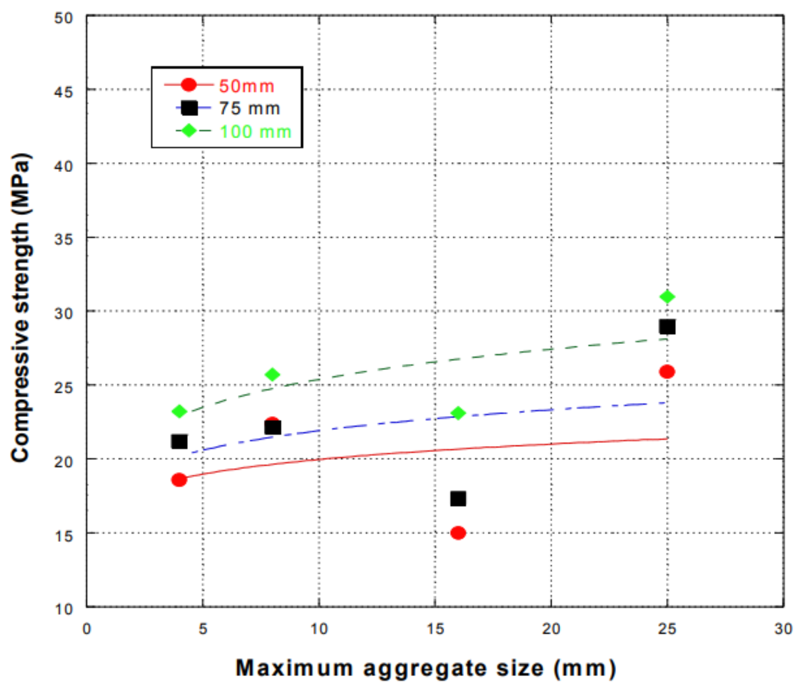
Graph b/w Relative strength & Aspect ratio (L/D)

Ratio amid length & diameter	Correction Factor of strength
1	0.8
1.2	0.9
1.5	0.9
1.7	0.9

Table 3. Strength correction factors for ration amid length and diameter according to ASTM C 42

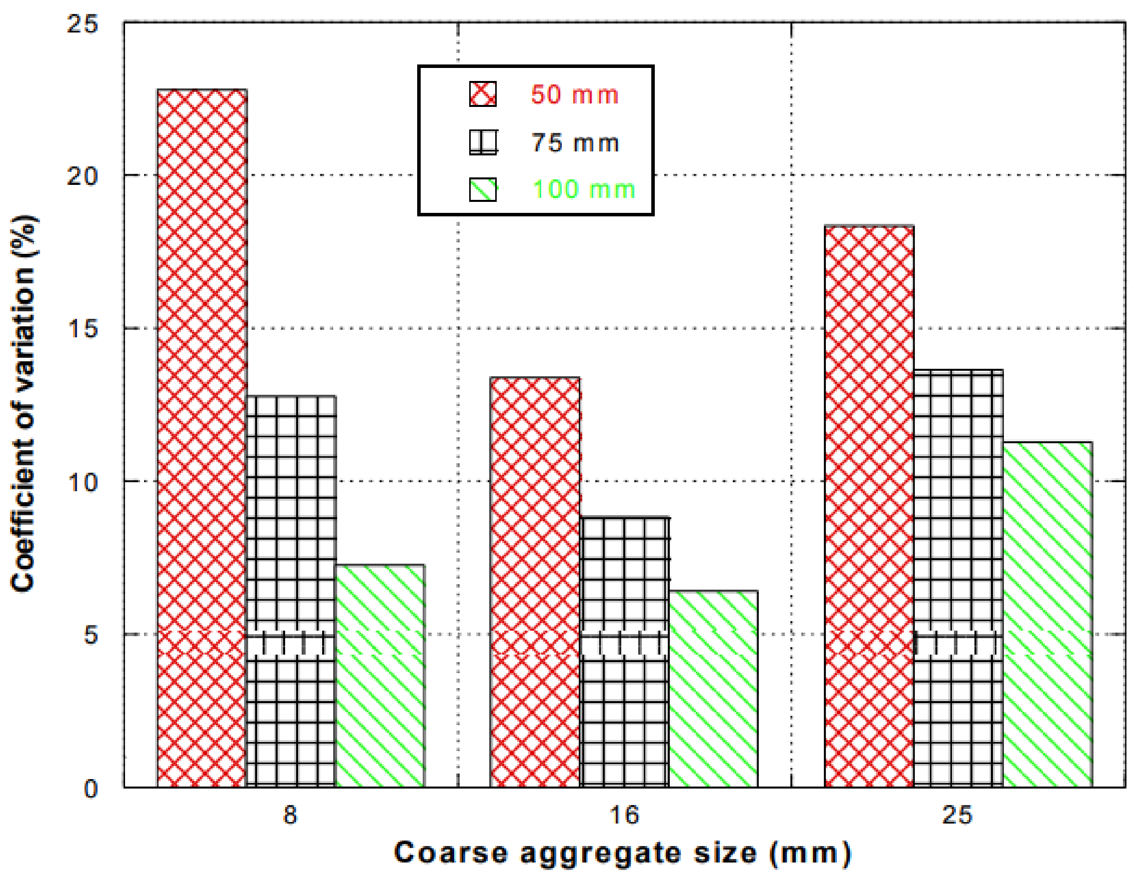
Aggregate size & core strength:

The strength of concrete core rises with rise in aggregate magnitude. With an amassing aggregate content, the compressive strength of a core rises. The graph doesn't show proportional relationship between aggregate size and concrete core strength. With the increasing aggregate size, max compressive strength occurs when aggregate size is 25 mm, but the compressive strength at 4 and 8 mm aggregate size is greater as compared to when aggregate size is 16mm.



Graph b/w max.aggregate size & compressive strength

The coefficient of variation (CoV) helps us to understand the role of max aggregate size in determining core compressive strength. With the increasing coarse aggregate size, the CoV decreases, thus increasing the density of concrete & stabling compressive strength. For small cores (50mm), the dispersion in strength is greater as compared to larger cores (100mm, 150mm).



Relationship between aggregate size & CoV (%)

Concrete Age:

The in-situ concrete strength increases slightly after 28 days. Tests have revealed that the core strength keep increasing up to 1 year, but that increase is very small compared to strength at 28 days. Studies have suggested that increase in core strength above 28 days is as follows:

Time duration	Increase in core strength (%)
3 months	10%
6 months	15%

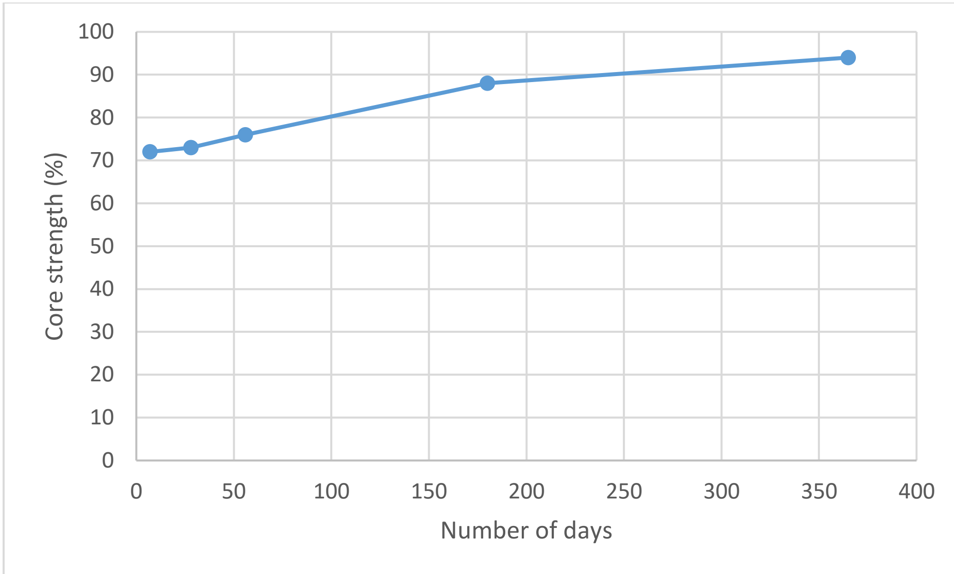
Table 4. Increase in core strength with time

S. No	Time period/days	Strength in Mega Pascal		Strength of core (% of 28 days standard cylinder strength)
		Normal/Cylinder.	Core.	
1	7	66.1	57.8	72.1%
2	28	80.6	58.6	73.2%
3	56	86.2	61.4	76.3%
4	180	97.8	70.5	88.3%
5	365	101.4	75.5	94.1%

Table 5. Core strength w.r.t time

Core strength vs Age(days)

Increase in strength (%) after 28 days



Graph b/w core strength & no. of days

Outcomes of Environmental Conditions on Strength of Concrete

Concrete is always vulnerable to attacks by many deteriorating agents during its life cycle, this totally depends on type of its application and where it is used. Many corrosive agents such as acids and different harmful salts can cause disastrous effect on concrete and deteriorate it significantly. This decay is directly proportional to amount of deteriorating agents and the time during which it is exposed. The higher the concentration of agents,the higher the decay. The greater the exposure, the greater the decay

The two notable factors to cause decay over time are sulphate attacks and freeze thaw action. So here comes the importance of durability which is defined as ability to withstand such factors which cause its deterioration. This is considered as important as the strength.

Effects of Sulphates

The mechanism of sulphate attacks is considered very complex and a lot of research going on in this particular field. The sulphates accumulate within concrete which then cause their aggressive action. The sources of popular sulphate like sodium, magnesium and calcium sulphates are groundwater and some types of soils. The damage is induced due to their penetration and accumulation within the concrete. The following reaction takes place

$$CH + N\bar{S} + 2H \rightarrow C\bar{S}H_2 + NH$$

$$C_4A\bar{S}H_{12} + 2C\bar{S}H_2 + 16H \rightarrow C_6A\bar{S}_3H_{32}$$

$$(C : CaO, N : Na, \bar{S} : SO_3, H : H_2O, A : Al_2O_3)$$

The calcium hydroxide which is present in hardened cement paste reacts with sulphate to form gypsum which in return reacts with unstable $C_4ASH_{12}(4CaO.Al_2O_3.SO_3.12H_2O)$ and as result ettringite is formed which is known for its too much capacity of swelling. As exposure is increased, more sulphate reaction takes place which causes damage.

Well this can be controlled significantly by choosing right type of cement. High strength concrete which contains combination of silica fume and natural pozzolans not only give higher strength but also plays important role in sulphate attack resistance and give more durability.

Effects of Frost Action

The rate of reaction between water and cement depends of temperature and has direct relation. Lower Temperature means lower rate of activity. After certain limit , the reaction stops. The water in pores freezes and this leads to about 9% increase in volume. This results in hydraulic pressure on non-frozen water in pores. Now the cement paste is under pressure. However the stresses are released as temperature increases. If thaw is followed by refreezing, stresses are create again and this results in deterioration.

Investigations show that level of damage is increased significantly in presence of both load and freeze-thaw for example highway, roads, bridges etc. Moreover, chemical reaction added with other agents can be catastrophic. So strength matters a lot here .Higher strength leads to higher resistance against deteriorating agents. Research shows that in high strength concrete only 10-15% strength is reduced after 700 cycles.

CONCLUSION:

Based on the literature review, we draw following conclusion:

1. For assessing the concrete quality, core test is the best solution. Core test becomes necessary in certain conditions for security valuation of the structure.
2. There will be an increase in the strength of core with a decrease in length to diameter ratio. For high strength concrete cores, the aspect ratio (L/D) doesn’t effect that much.
3. Core strength decreases with the decrease in core dimeter. Cores with diameter less than 100mm have shown up to 17% strength reduction.
4. For low strength concrete (18MPa), the strength reduction factor due to drilling is considerable. This is because during drilling the bond between aggregate & cement gets weakened.
5. Drilling direction has a direct impact on core strength. Cores drilled vertically have greater strength than those drilled horizontally.
6. Concrete cores having reinforcement steel account for strength reduction. A core containing a bar of 22mm accounts for strength reduction up to 25%.
7. Core moisture levels affect the core strength. Core specimens dried for 7 days showed 12% increase in strength.
8. Among different code, ACI codes seems to be satisfactory provided no steel is present in the concrete cores.

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Pile rafts and Compensated Pile rafts

Project Advisor: Maj. Dr.Rizwan

Syndicate members:

NS-3893 M. Tayyab Amin (183089)

NS-3913 Fasih-ur-Rehman (197477)

NS-3910 Arslan Tahir Bajwa (190449)

NS-3904 Hamza Arif (196414)

ASC-2572 Muhammad Ukasha (201341)

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Abstract:
Since the population is increasing at drastic rate and this is resulting in scarcity of good soils and appropriate site for construction. The Building is completely based on its foundation which in return depends on the condition and type of soil. Now to meet the demand of ever increasing population, construction is required to be done on the soft soils. This indicates the importance of both conventional and compensated pile rafts to support the structure on the soft soils. There are two cases which are addressed here in this project. First are just the applied loads acting on foundation and the other one is applied loads along with the ground settlement. The places where there is abundant soft soil, the chances of differential settlement increases significantly. This can be avoided using compensated pile rafts. Here the soil is excavated and raft is embedded. Researches have shown that this can significantly reduce the effects of ground settlement, leading up to the differential settlements.

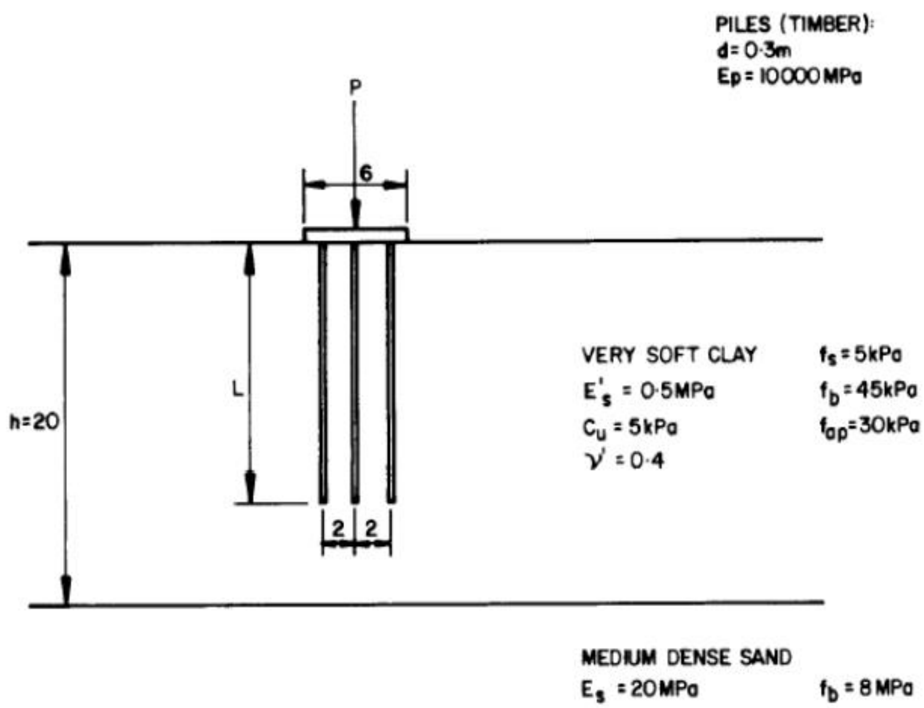
Introduction:
Pile Rafts are comparatively inexpensive when the soil beneath have strength and can provide significant bearing capacity (Randolph, 1994; Katzenbach et al, 1998, Poulos, 2001). But here is problem that many designers do not prefer pile rafts for following two reasons.

1. Soft Clays do not provide enough bearing capacity leaving piles to carry a lot of loads
2. High Tendency of soft clays to settle again leaving high loads on piles alone.

Because of high need of building structures on soft clays . This project will high light the importance of pile raft and compensated pile rafts and answer the following questions:

1. **<u>How Pile rafts act in soft clays without excavation and settlements?</u>**
2. **<u>How compensated pile raft behave on soft clays?</u>**
3. **<u>How ground Settlement affect the performance of pile raft?</u>**

How Pile rafts act in soft clays without excavation and settlements.



<u>Figure 1</u>

Here to answer the first question, The above figure has been used for analysis

Some key features in diagram are as follows:

1. **L= length of piles**

2. **D= Pile diameter**
3. **E_p = Pile Young modulus**
4. **H= Soil Layer depth**
5. **E_s = Young Modulus of drained soil**
6. **V= Poisson ratio**
7. **cu=undrained shear strength of soil**
8. **fs=ultimate shaft friction**
9. **fb=ultimate end bearing capacity of pile**
10. **fap=ultimate bearing capacity of raft**
11. In this problem a square raft is considered having 300mm diameter 9 piles. The analysis is done using computer software called PRAWN.

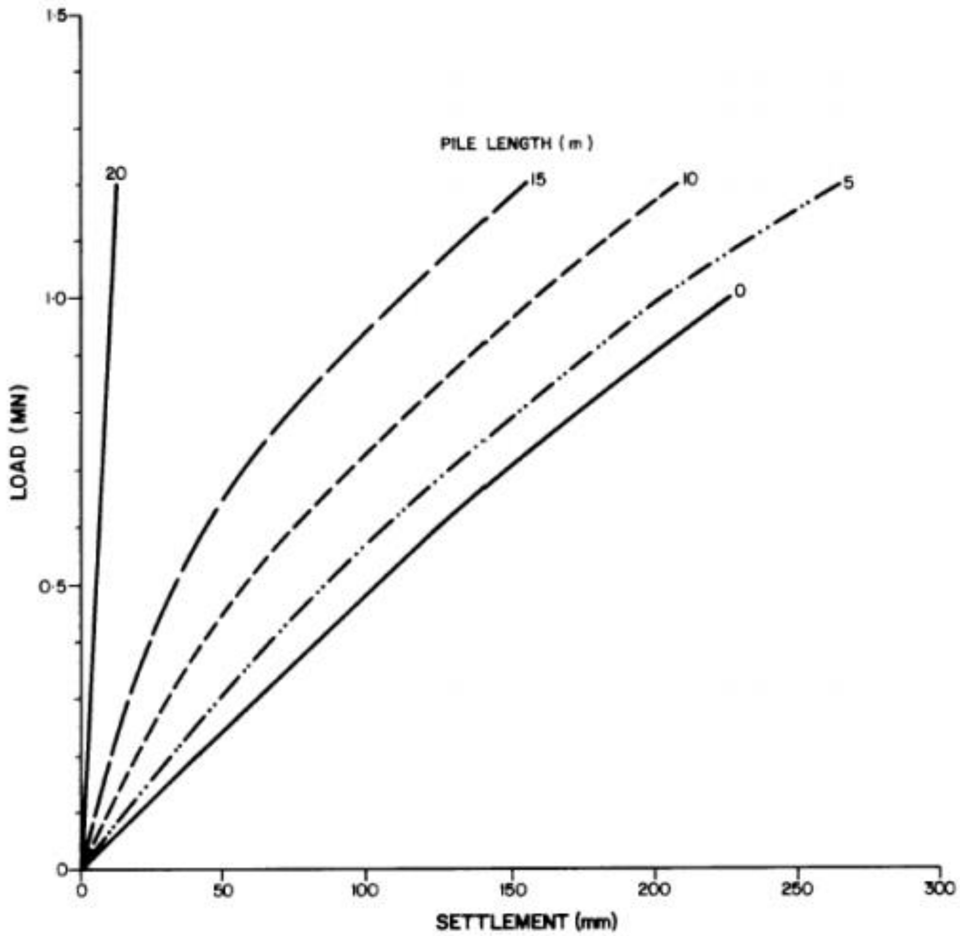


Figure:2

The above figure shows the curves representing load settlements, they are for various pile lengths from 0 to 20. This is clearly shown here that settlement decreases with increase in pile lengths. Piles have to be end bearing if substantial reduction in settlement in required.

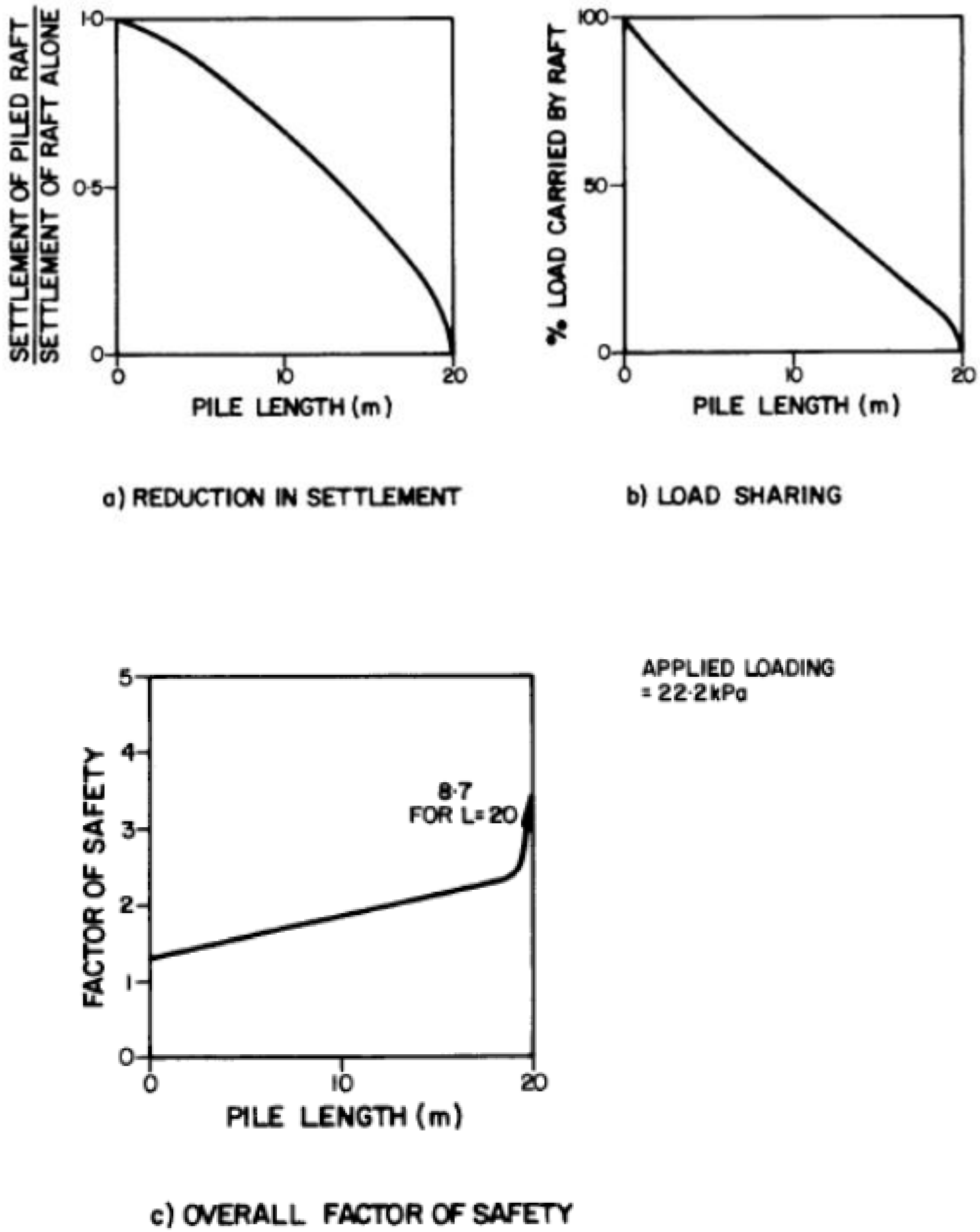


Figure:3

In figure 3, it is quite obvious that increase in number of piles not only increases stiffness but also factor of safety but settlement is still quite large until and unless the piles are end bearing. In cases like these, raft carries no load or almost no load.

How compensated pile raft behave on soft clays?

In this case, first the soils excavated and then the raft is embedded in order to reduce the applied load on the soil beneath the raft. This practice significantly reduces the effective vertical stresses and this result in less settlement of soil.

1. Maximum Excavation Depth

If sides of excavation are supported and if no piles are present, the maximum depth of excavation depends on bottom heave consideration. Researches have shown that factors of safety vary from case to case. For instance, in case of deep layer of soft soil, the factor of safety decreases with increases in depth but increases with increase in width. This situation is for those soft soils whose undrained shear strength increases with depth.

In the cases, where piles are installed before excavation, we have to find equivalent expression for pile reinforced soil and this in return can be of use in conventional equations.

In case of deep clay layer, the expression derived from Davis and booker can be utilized in finding the foundation bearing capacity of footing on equivalent soil mass with crust. The following expression can be derived for equivalent cohesion for vertical loading of reinforced soil:

$$c_{ev} = \frac{1}{N_c}\left[\frac{P_{vu}}{F.Ar} - \frac{pB}{t}\right] \quad (1)$$

where N_c = bearing capacity factor (5.14 for strip foundations, 6 for circular foundations)

P_{vu} = ultimate vertical bearing capacity of the piled foundation

F = correction factor, which can be approximated as 1.0 for many cases

Ar = plan area of footing or raft

P = rate of increase of soil shear strength with depth

B = footing or raft width

t = shape factor (4 for strip, 6 for circular foundation).

Where P_{vu} is calculated with the help of pile capacity theory.

Researches also show that Factor is directly proportional to pile length and inversely proportional to pile spacing. This means that FOS tends to increase when pile length are increased however FOS is also increased when pile spacing is reduced.

Compensated Pile Raft Analysis Results:

Analysis of simple problem shown in figure 1 has been done. This is done in order to check how excavation affects the behavior of foundation. This helped us to make following assumptions:

1. **Soils Young Modulus:** The reloading and unloading Soils Young Modulus is 5 times first load modulus
2. **Piles installation:** Before taking out the soil or in other words Excavation, piles should be installed

3. **Ground Surface Heave:** With the help of simple elastic analysis, the ground surface heave is calculated and researches show that it decreases with depth.

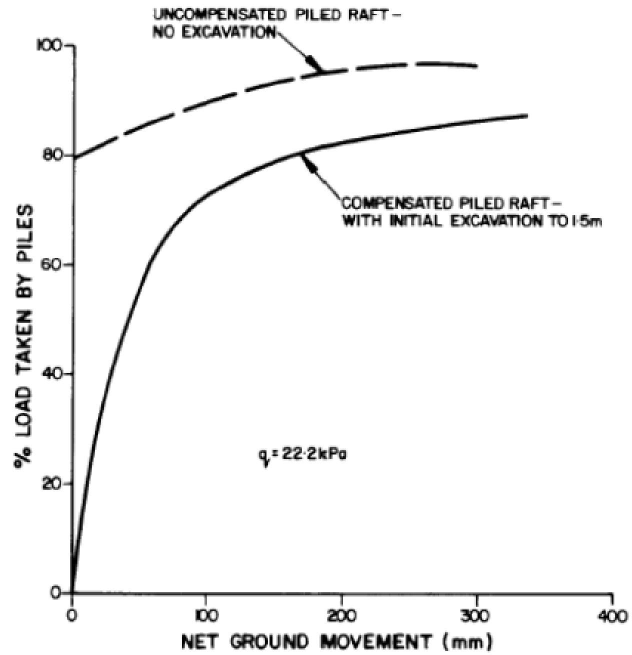


Figure 4

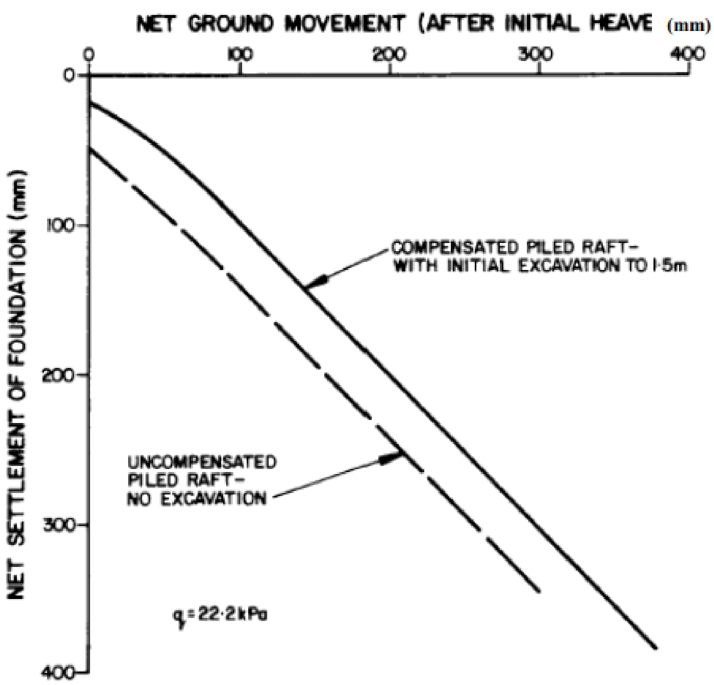


Figure 5

The Figure 4 is presentation of foundation settlement as a function of net ground movement after the very first ground heave. This shows calculated foundation settlement due to excavation of soil up to 1.5 meter. Figure 4 also represents the case where there is no excavation. Figure 5 shows the part of applied load carried by piles.

Observations

From above experiment, here are observations which are listed below:

1. With the increase in ground settlement, piles have to carry more percent of load.
2. In case of compensated pile rafts, the settlement of foundation is almost equivalent to ground settlement. So almost no differential settlement of overall structure.
3. Thses compensated pile rafts baer a lot less settlement as compare to other foundation systems.
4. In case of compensated foundation, piles have to carry a lot less loads.

How pile rafts can be made economical?

In order to answer the above question, we have to know what are task carried out in laying pile rafts. The cost is divided among two most prominent sections which are:

1. Construction Labor
2. Materials required for construction.

Then 3 more tasks are carried out while laying the pile rafts which are also listed below:

1. Installation
2. Reinforcement
3. Concrete.

In design of any structure, two primary concerns for any designer are safety and economy and both require optimization in the design process. Since the trends of high rise buildings is increasing in the world and high rise building usually stands on piles and pile rafts. This also indicates the importance of research about how to economize the whole design process without compromising the overall safety.

Conclusion & Recommendation:

1. Spacing of piles play very critical role not only to avoid settlement but also on the cost.
2. Pile length is also very critical. Their lengths play important role to reduce the differential settlements, but researches show that beyond certain limit the their length have least effect. So pile lengths should only be increased at places which are more vulnerable to settlement.
3. One more thing to note is change in load type is effective on differential settlement and raft maximum moment. The effect of load type on pile raft settlement increases by enhancing soil SPT. This effect on maximum settlement in negligible but cannot be ignored for differential settlement and maximum moment.

So to conclude, it is suggested that according to given condition, the optimum pile arrangement should be used with appropriate spacing and pile length in order to achieve maximum safety with minimum possible cost.

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