Effect on Seismic Response of a Reinforced Concrete Frame Structure Subjected to Sulphate Attack

Final Year Project UG-2015

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This is to certify that the

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"In the name of Allah, the most beneficent, the most merciful"

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Completion of this research work is the outcome of co-operation of many supportive people. It is hard to measure their assistances. Besides our supervisor we would also like to thank Mr. Atif Mehmood Khan. Finally we are thankful to our parents who were always supportive and encouraged us during intervals of work stress.

Table of Contents

Table of Figures

ABSTRACT

Reinforced Concrete is widely used material in buildings, bridges and dams due to its speed of construction, flexibility, sustainability and easiness to cast. It is the first choice of civil engineers worldwide. But there are certain phenomena which cause spalling, cracking and deterioration of concrete, one of which is sulphate attack either in the form of acid rain, acid sulphate soils or sulphate enriched sewerage water. Furthermore RC structures in Pakistan are subjected to persistent cycles of extremely hot and cold climate which encourage the progress of sulphate attack. Current research work and observation indicates that parts of Islamic Republic of Pakistan are seismically active and have low to medium seismic regions. Common construction practice observed for RC structures in Pakistan is that they are only designed for gravity loads. Such structures are also subjected to wind and lateral loads. In such conditions RC structures subjected to Sulphate attack in cities like Faisalabad, Karachi and Gawadar are prone to failure in case of an Earthquake. This study aims to quantify the damage caused by sulphate attack and its effect on seismic response of Reinforced Concrete frame structure which will help engineers decide whether to demolish or retrofit a structure exposed to sulphate attack.

1 INTRODUCTION

1.1 GENERAL:

Reinforced Concrete has been in use for centuries as a major construction material because of its variety of benefits. It has significant strength in compression and also in tension because of embedded steel reinforcement which gives it an edge over other materials. It can resist normal weather conditions but phenomena like sulphate attack and corrosion are its greatest weakness because both reduces compressive strength of concrete and yielding strength of rebar.

Sulphate attack is the reaction of sulphate ions with C-S-H and C-A-H in the cement matrix. This reaction causes creation of ettringite which exerts immense pressure on the pores. This pressure causes cracking and erosion of concrete. It is very harmful for RC structures because it slowly dissolves the cement paste holding aggregate together and then makes its way to rebar and start dissolving it. With passage of time area of rebar reduces which in turn reduces the yielding strength of rebar.

Sulphate attack depends on many parameters including cement type and exposure conditions and in countries like Pakistan all conditions which facilitate Sulphate attack are present. In industrial cities like Faisalabad because of severe air pollution the phenomena of acid rain is very much common which is a form of sulphate attack. If we look towards weather conditions which acts as catalyst for sulphate attack, RC structures in Pakistan encounter persistent cycles of extremely hot and cold climate which encourage the progress of sulphate attack. Sulphate ions in ground water, sea water and decaying organic matter are also a threat to the durability of the structure and more over in Pakistan Acid Sulphate soils are wide spread.

Acid Sulphate soils are the soils with sufficient sulphides which have a tendency to become strongly acidic when reacted with salt water and sewage water. In Coastal areas like Karachi and Gawadar these soils are very prominent so RC structures in these regions are highly subjected to Sulphate attack. Also waste water management system of Pakistan is inefficient so Sulphate enriched sewage water also contributes in the formation of Acid Sulphate Soils. Sadly in Pakistan despite of the dangers to RC structures due to Sulphate attack there are no proper practices involved in its monitoring and curing.

Earthquakes are a great danger to man-made structures. It is a force majeure phenomena which we can neither control nor can stop from happening but we can make our buildings more resistant toward seismic activity by understanding what they are, how they happen, what are the factors that control them and how they affect structures and determine which procedures or materials can respond better to seismic activity etc.

The major research in field of Earthquakes started since last century because of deadly and horrible Earthquakes of likes Chile 1960:9.5(5,700 killed), Japan 2011:9.1(18,500 killed), Indonesia 2004:9.1(1,68,000 killed), China 1976:7.4 (2,42,000 killed), China 1920 (2,35,000 killed) which results in huge loss of life and economy. This loss was due to the poor construction practices and non-engineered structures especially in developing countries of Pakistan alike in which there are no guidelines or proper building codes to design buildings that can sustain earthquake loads in addition to gravity loads. Also the concept of proper structural Health Monitoring and routine maintenance is new or very less practiced in developing countries.

Pakistan lies on three tectonic plates. The majority of regions face the risk of moderate to high level of earthquakes. For example Kashmir earthquake that took place on 8 October 2005 in which 86,000 people were killed. Kashmir earthquake was an eye opener for the Government and also for the researchers to update and improve their knowledge and engineering practices to minimize damage in case of a future earth quake. In order to avoid such catastrophes in future Seismic Monitoring Network under the supervision of Pakistan Meteorological Department (PMD) was developed to record and monitor the seismic activity. It is impossible to fully diminish the effects of Earthquake bur certain measures like Shock Absorbers and Tuned mass dampers can mitigate it.

Sulphate attack affects the Energy absorption capacity and base shear of the buildings by reducing the compressive strength of concrete and yielding strength of rebar. This reduction results in demolishing of RC Frame structures which are under seismic loading.

1.2 Problem Statement:

The phenomena of Sulphate attack on RC structures is very common in Pakistan because of acid rain, acid-sulphate soils, poor waste and sewage water management and weather conditions . Also Pakistan is a seismically active region so under seismic loading structures exposed to Sulphate attack may collapse .So, there is a need of thorough study to quantify the effect on seismic behavior of RC structures at various stages of sulphate attack.

1.3 Work Procedure:

To calculate the effect on seismic response of RC Frame structure subjected to sulphate attack the following steps are carried out.

- Procurement of materials i.e. cement, sand, coarse aggregate, PVC drum, 98% concentrated sulphuric acid, steel rebar and steel reinforcement cages.
- Casting of 6 PCC and 6 RCC cylinders.
- Compressive testing of 3 PCC and 3 RCC cylinders after 28 days of curing and yielding strength testing on rebar to find the control sample properties.
- Making of a sulphate medium by mixing sulphuric acid with water in PVC drum
- Immersing 3 cured (28 days) PCC and RCC samples and 12 #4 steel rebar in sulphate medium
- Giving wet(4.5 days) and dry (2.5 days) cycles to steel rebar and cylinders for 30 days after which 1 PCC and 1 RCC cylinder was tested in compression testing machine and steel rebar were tested in UTM machine.
- The same process was repeated after 60 and 120 days of exposure to sulphate attack and similar testing was performed on the samples.
- After experimental phase values from the stress-strain curves of concrete and steel rebar was use for the development of 4 moment curvature (M-Phi) curves at 0, 30, 60 and 120 days of exposure to sulphate attack.
- Calculation of Energy-Absorption capacity of RC frame structure from Moment-Curvature curves at 4 stages.
- Selection of a 3-storey building.
- Structural Modeling of selected building on SAP2000 using base material properties

- Modifying the hinge properties in SAP2000 by inputting moment curvature curve
- Gravity analysis of a building
- Pushover analysis of a building using SAP2000
- Pushover analysis of 30 ,60 and 120 days model having same building characteristics but different material and hinge properties in SAP2000
- Compilation and comparison of results
- Conclusions and recommendations

1.4 Aims & Objectives:

The focal aims of this study are:

- To get a deep understanding of sulphate attack on RC frame structures.
- Study and comparison of the seismic response of structures at 0, 30, 60 and 120 days of exposure to sulphate attack.
- This study will tell us the change in material properties of Reinforced Concrete and hence the change in the seismic response of buildings at various stages of sulphate attack.
- This study will also help the professionals to decide whether to go for Retrofitting or not to improve seismic performance.

The main objectives includes:

- To quantify the materials strength properties of reinforced concrete at various stages of sulphate attack
- To study the behavior of structures under seismic loading by pushover analysis using sap 2000 at various stages of sulphate attack.

1.5 Utilization:

The research can be utilized to quantify the seismic response of a frame structure under sulphate attack in terms of base shear and energy absorption capacity. It can also be used as an input to decide which retrofitting material is best suited for the treatment of a building under sulphate attack. It can be used by local authorities in Structural Health Monitoring (SHM) to see whether a building can sustain future predicted Earthquake loadings or not and to determine whether it is safe for occupancy or they should rehabilitate or demolish it

2. Literature Review

2.1 Introduction:

Sulphate attack is an arising issue that effects the structures' durability as well as different parameters related to its strength especially its seismic capacity. There are several reasons of sulphate attack. The external sulphate attack takes place due to presence of sulphates in the atmosphere, seawater or groundwater. The internal sulphate attack on reinforced cement concrete is due to several reasons including the deterioration of already present primary ettringite, sulphate released by contaminated source of aggregates with cement or gypsum. Sulphate attack expands the concrete at first, followed by cracking and spalling of concrete and thus reducing the overall mass of concrete. This reduces the strength of concrete thus reducing the seismic capacity or the capability of structures to resist earthquake loading. The reduction in seismic capacity leads to the possible risk of collapse of the structure due to an earthquake. The study of reduction in strength due to sulphate attack on RCC structures and the ways we can retrofit that damage are the objectives of our project.

2.2 Inhibiting sulphate attack on concrete by hydrophobic green plant extract:

Advanced Materials Research, Vol. 250-253, (2011), pp 3837-3843, M. Ismail et al.

CONCLUSIONS:

The design of concrete members that have high durability level and protection from various deleterious forces of nature has increased due to structures built in harsh environments, the overall structure's integrity remains protected.

The structures built in these harsh environments are prone to sulphate ions in groundwater, sea-water and decaying organic matter are a threat to durability of concrete structures. These sulphate ions penetrate into the concrete members and interact with the cement matrix generating cracks and strength loss of concrete.

2.3 Ettringite-cause of damage, damage intensifier or uninvolved third party:

ZKG International, V. 51, No. 5, 1998, pp. 280-292. Stark, J., Bollmann, K. And Seyfarth, K.

CONCLUSIONS:

The ettringite formation that is formed at later stages after several months or years is the secondary stage of ettringite formation, also termed as Delayed Ettringite Formation. The hardened and rigid concrete members can create cracks within concrete which in result causes spalling of concrete that damages the strength of those concrete members.

2.4 Plausibility of delayed ettringite formation as a distress mechanism-consideration at ambient and elevated temperatures:

Proceedings, 10^{th} International Congress on the Chemistry of Cement, Gothenburg, Sweeden, 4i 59, 1997, pp. 10, Klemm, W.A and Millers, F.M.

CONCLUSIONS:

The paste of cement contacts with the water or soil that is rich in ions of sulphate, determines the extent of External Sulphate Attack. The soils containing calcium, magnesium and sodium sulphates are the major sources of sulphate ions that becomes the root-cause for the External Sulphate Attack.

2.5 Physiochemical and mechanical properties of Portland cements:

lea's chemistry of cement and concrete (4th ed.), arnold publisher (1998), pp. 343-419, p.c. hewlett.

CONCLUSIONS:

The internal cement matrix changes to ettringite when calcium aluminate hydrates and mono-sulphate hydrates reacts with the sulphate ions source and expands the concrete, this expansion is the cause of crack generation and spalling of concrete is the following process.

$$\begin{matrix} C_3A.CS.H_{12\text{-}18} \\ C\text{-}A\text{-}H \end{matrix} \xrightarrow[H_2O]{CSH_2} \begin{matrix} C_3A.CS.H_{32} \\ \text{(ettringite)} \end{matrix}$$

2.6 Effect of carbonation, chloride and sulphate attacks on reinforced concrete: a review:

International Journal of Civil Engineering, Construction and Estate Management, Vol. 6, No.2, pp.59-64, July 2018, Published by European for Research Training and Development UK.

CONCLUSIONS:

The parameters that decides the deterioration mechanism are exposure conditions and material constituents. There are a number of reasons for the initiation of chemical attack on concrete structures which includes inappropriate choice of cement type with respect to exposure conditions, high concrete permeability and porosity, cement content, quality and type of constituent material.

2.7 Concrete deterioration caused by sulfuric acid attack:

TTI-199, K. Kawai, S. Yamaji and T. Shinmi.

CONCLUSIONS:

The rate of concrete deterioration is directly proportional to the concentration of acid. At higher concentrations the depth of erosion of concrete is directly proportional to the time of exposure rather than the square-root of exposure time.

2.8 Electrochemical investigation on corrosion behavior of reinforcing steel in concrete exposed to sulphuric acid:

Construction and Building Materials, 49(2013), 471–477, Husnu Gerengi etal (2013)

CONCLUSIONS:

Sulphuric acid that is produced from the sewage or Sulphur di oxide present in the atmosphere that reacts with rain to form an acid rain can attack the concrete. The main reason for the corrosion is destruction of rebar due to the acid rain which is the result of reaction between the Sulphur di oxide present in the atmosphere and the rain molecules. The major controlling factor for the initiation of corrosion is porosity i.e. more the porosity, the concrete is more prone to the attack as the sulphuric acid intrudes and attacks the rebar.

2.9 Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings:

Mehmet Inel Pamukkale University. Hayri Baytan Ozmen Usak Üniversitesi

CONCLUSIONS:

The base shear capacity of RC structures is not dependent on type of hinge i.e. whether we use user-defined hinge or a default one. Even for building models with different transverse reinforcement spacing and plastic hinge length, comparison of analysis and results for default and user-defined hinges prove that their base shear capacity is almost same with a variation of less than 5% which can be neglected. But there is a significant effect of length of Plastic hinges on the displacement capacity of the RC frames. Results have proven a variation of nearly 30% in displacement of RC frame due to change in the values of length of a hinge. Displacement capacity is directly proportional to transverse reinforcement and is improved by it. This improvement is less effective in case of larger spacing of transverse reinforcement and more in case of smaller spacing. As far as hinging patterns are concerned at the yielding state, models with default and user-defined hinges estimate plastic hinge formation while differences are observed in the ultimate state.

2.10 Practical Three Dimensional Nonlinear Static Pushover Analysis:

Ashraf Habibullah etal Computers and Structures, Inc., Berkeley, CA

CONCLUSIONS:

Pushover load cases can be of two types i.e. force controlled and displacement controlled. In force controlled load case of push over analysis building model is pushed to a certain level of force which is pre-defined e.g. a gravity load push over while in case of displacement controlled case building model is pushed to a specified displacement e.g. lateral push over. If you want to make a building stiff you can do so by changing its properties also by changing the hinge acceptance criteria you can change the initial characteristics of the model.

3. Experimentation

3.1 Introduction:

A total of 12 standard samples of 6” diameter and 12” height were casted using the same materials and under same conditions. Six sample of Portland Cement Concrete (PCC) and six samples of Reinforced Cement Concrete (RCC) with 4 #1 bars as main reinforcement and #1 bars as lateral reinforcement with a spacing of 3” were casted. A Sulphate medium was developed by mixing 98% concentrated sulphuric acid in water to make a 4.7 Molar Sulphate solution in a PVC drum. 3 cylinders of PCC, 3 cylinders of RCC and #4 steel rebar of 2 feet length were placed in the medium.

3.2 Materials:

3.2.1 Sulphuric Acid:

Sulphuric acid was selected as an agent for making sulphate medium because of its heavy presence in the Acid Rain, Sewerage and Acid sulphate soils. Concentration of Sulphuric acid solution was taken to be 25%. The solution was 4.7 Molar which is less than 5 M which is the limit to ensure that the acid reacts with the Concrete and steel the same way as it does in the field. Ph. of 1 was kept to make sure faster Attack rate because of time Constraint.

3.2.2 Steel:

In the samples of RCC, #1 Grade 60 steel was used as longitudinal and lateral reinforcement.

While 12 # 4 Grade 60 Rebar of 2 feet length were used to see and quantify the effect of sulphate attack on steel bars at specified intervals. 4 bars were tested at 30, 60 and 120 days interval each and a mean value of Yielding strength was used. The difference in area of cross section and weight of rebar was also observed due to which reduction in strength was observed.

Figure 1 #1 RCC Reinforcement

Figure 2 #4 Reinforcement

3.2.3 Concrete:

Concrete with compressive Strength of 3000 psi was used and its mix design was of 1: 1.5: 3(cement: sand: gravel) by weight. The aggregate used was well graded aggregate. Quality control was uphold for sand and cement. The mix design of 1:1.5:3and compressive strength of 3000 psi was selected keeping in view the fact that these standards are generally exercised in Pakistan for multistory buildings.

3.3 Instrumentation:

3.3.1 Sulphate attack:

The Concrete (3 PCC and 3 RCC) and Steel rebar (12 #4) samples were placed in the Sulphuric acid. All the samples were given wet and dry cycles to ensure that the attack is as close to field behavior as possible. The Wet phase of cycle was taken to be 4.5 Days while Dry phase was 2.5 Days. The whole deterioration period took 4 months or 120 Days and we took samples at 4 intervals from start at no sulphate attack to form a base line to near extreme deterioration at which cement paste was completely dissolved (Figure 3 right cylinder) so we can see the behavior of Structure during its complete life under Sulphate attack. So, we took samples at intervals of 0 Days, 30 Days, 60 Days and 120 Days because of material and time constraint.

Figure 3 Sulphate medium and cylinders at 30 and 120 days exposure

3.3.2 Cylinders:

After 28 days of curing, Compression tests were performed on 3 PCC and 3 RCC cylinders using a Compression testing machine of 2000 KN capacity with a loading rate of 0.15 MPa/sec conforming to ASTM C39 standards. The results were used to find the mean compressive strength of base samples of PCC and RCC. Same test was performed on other samples after 30, 60 and 120 days of exposure to sulphate attack. Figure 4 shows the compression test setup and concrete cylinder undergoing the test. Progress of the test was monitored on the computer screen and all the load-deformation data was stored.

Figure 4 Specimen ready for testing with full set up

Compression Testing Results:

Figure 5 & 6 shows the Compressive Strength of all 4 samples of both RCC and PCC taken at the intervals of 0, 30, 60, 120 Days. We can see the Decrease in strength in each interval.

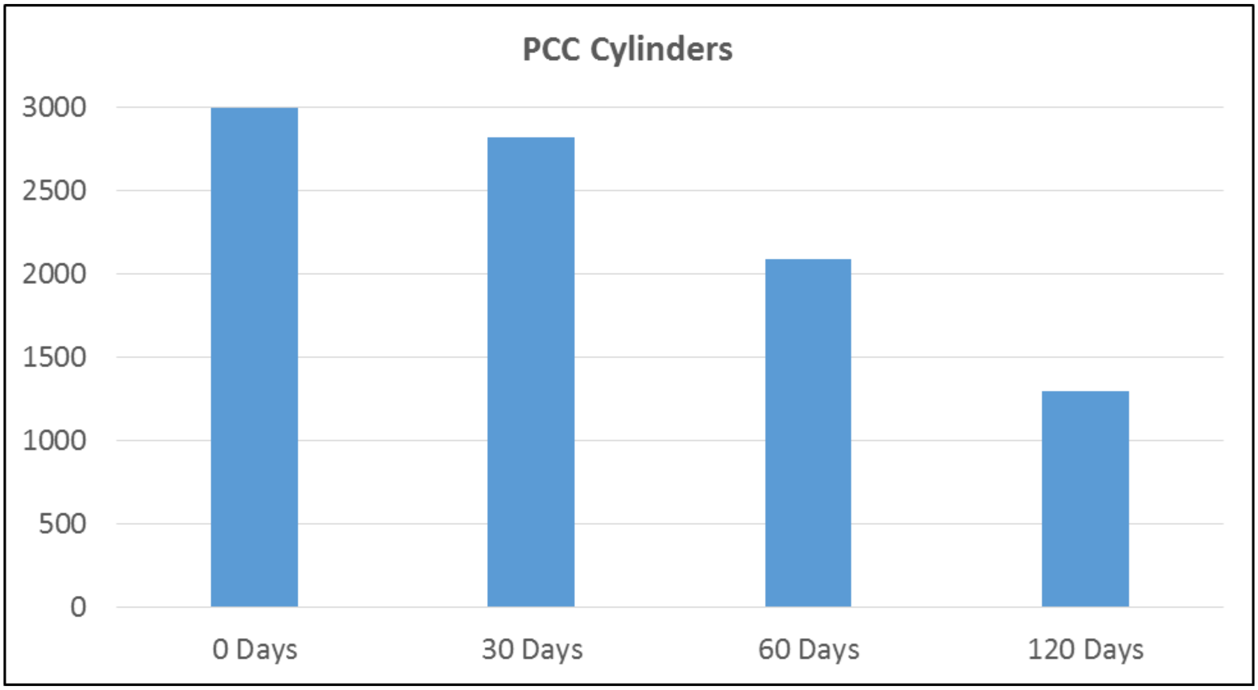


Figure 5 Compressive strength of PCC Samples

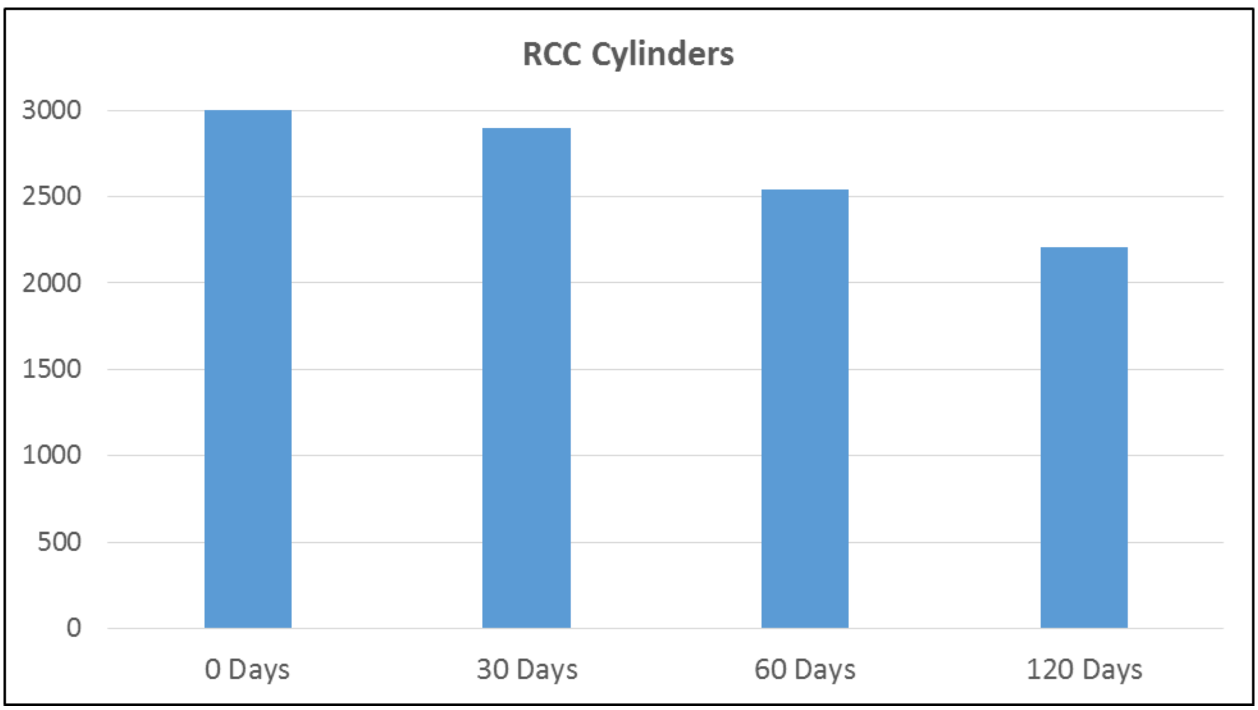


Figure 6 Compressive Strength of RCC Samples

From these graphs we can also conclude that confinement in Concrete slows the effect of sulphate attack that's why the decrease in strength of PCC columns is much more eminent then RCC columns. The reason for this difference is because of steel cages confinement in RCC columns. Sulphate attack affects the concrete by dissolving cement paste between aggregate which is responsible for holding the aggregate together and slowly makes its way by first dissolving cover and then moving to inner reinforcement. We observed that in case of RCC because of the confinement the cover got damaged but the inner core was firm because of additional stresses and these stresses are responsible for less reduction in strength in comparison to PCC cylinders.

3.3.3 Steel Rebar:

Tensile test were performed on the rebar to find their Yielding and Ultimate strength using Universal testing machine (UTM) according to ASTM a615 standard. The testing was performed for each stage of sulphate attack, the values obtained were used to select mean values and then stress-strain curve was established for those values. After which the same process was repeated for each set of rebar at later stages of sulphate attack and by overlaying the stress-strain curves for all stages we observe a decrease in strength as shown in Figure 7.

Tensile Testing Results:

As you can see from the stress strain graphs in Figure 7 there is extensive decrease in strength of bars after each interval because of sulphate attack.

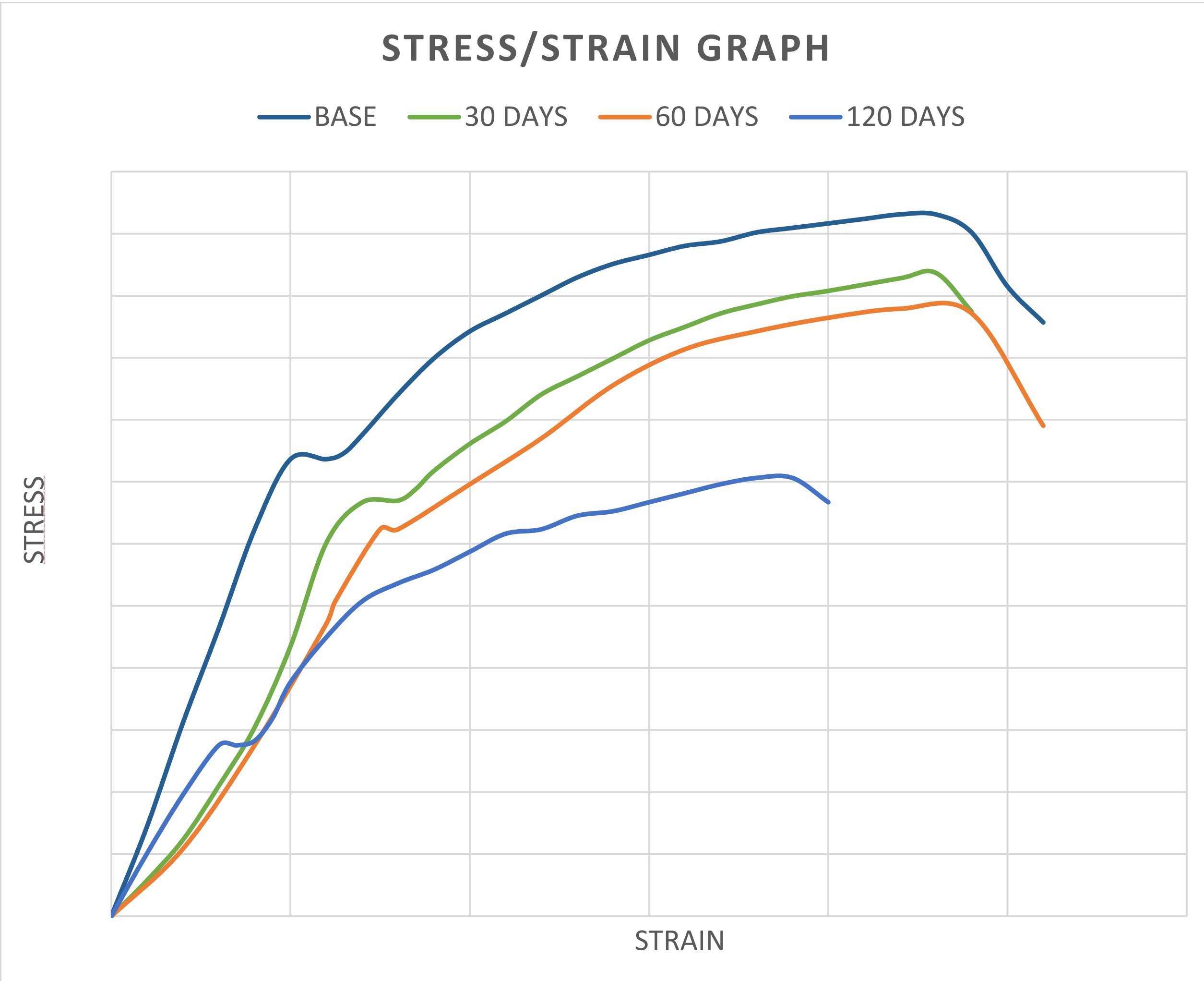


Figure 7 Stress-Strain curves for steel

The Chart in Figure 8 shows the yielding strength of Steel Rebar at 0, 30, 60 and 120 Days interval. The difference in strength was due to depletion in the cross-sectional area and loss of weight of rebar. The weight of steel bars was a good indicator in finding out whether steel bars are reacting with acid or not or whether they are getting affected by it or not.

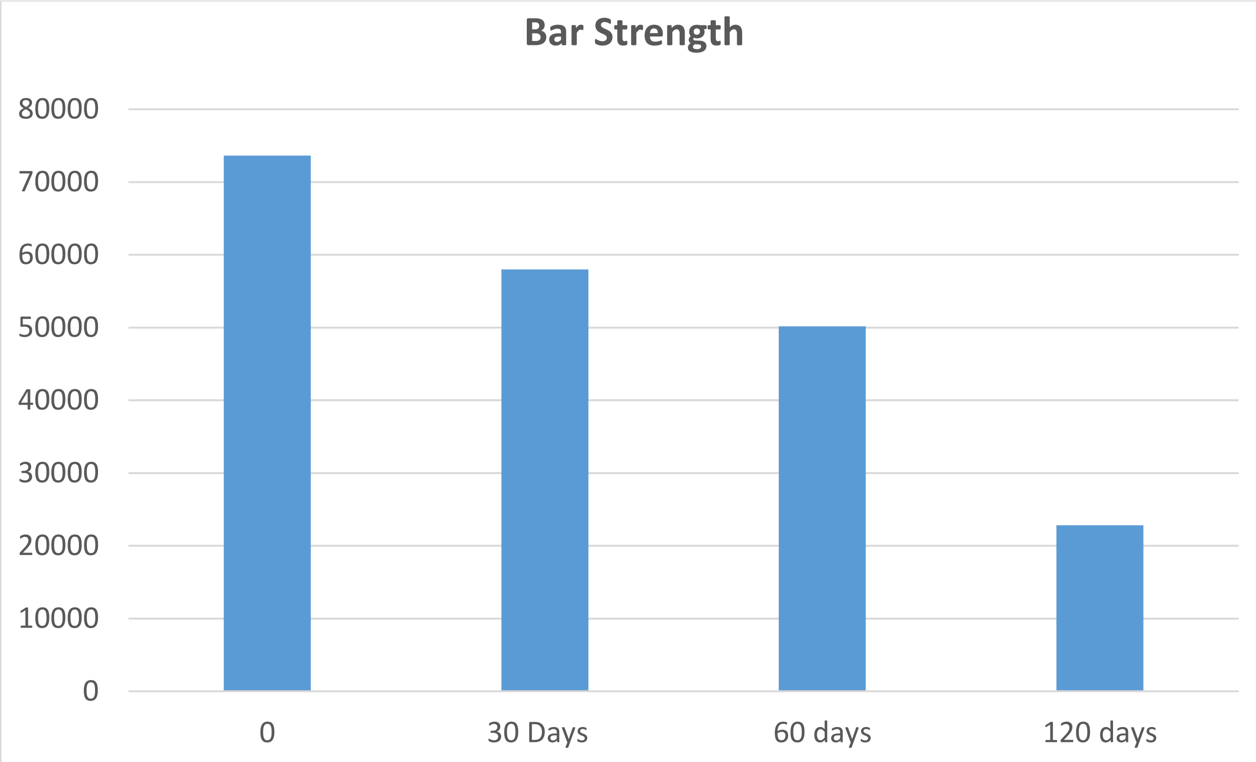


Figure 8 Yielding strength of rebar under sulphate attack

3.4 Moment Curvature Curve

Ec was calculated from $5700\sqrt{fc}$ in which fc is the strength of concrete at each stage of sulphate attack. As Ec is dependent on fc so a decrease in fc as observed in experimental phase and shown in Figure 5 will cause a decrease in Ec. Secant modulus of elasticity (Es) was extracted from the stress-strain curve of concrete and Yielding modulus of elasticity (Ey) was extracted from the stress-strain curves of steel as shown in Figure 7 for the formation of moment curvature curves or M-θ curve using Whitney Stress Block Equations as shown in Figure 9.

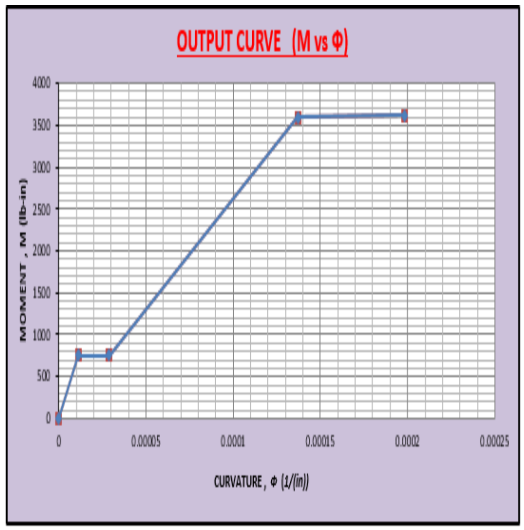
Figures 9 show the input parameters, output parameters and the associated moment curvature curve of base model at base material properties, the same process was repeated for 30, 60 and 120 days model and Moment Curvature graphs for each case were plotted. The input parameters include fc, fy of rebar, Ec, Secant modulus of concrete, width and depth of beam, cover of reinforcement, no of bars in beam, diameter of stirrup. The output parameters give you 5 points of inflexion say A, B, C, D, E .These points are same as shown in behavior of Hinge in Figure. These points will be used as inputs in defining user-defined hinges in push-over analysis.

INPUT PARAMETERS

MATERIAL PROPERTIES		DIMENSION PROPERTIES	
f'c (psi)	3000	b (in)	15
fy (psi)	60000	h (in)	25
η	9.284219976	d (in)	22.5625
ft (psi)	410.7919181	Cover (in)	1.5
Ec (ksi)	3122.018578	db (in)	1.125
Ey (ksi)	28985.50725	ds (in)	0.375
Esec(ksi	2175	No. of Bars	3
		As (sq.in)	2.98206563

OUTPUT PARAMETERS

Curvature (ϕ)	Moment (M)
0	0
1.10775E-05	756.3606525
2.88736E-05	756.3606525
0.000137129	3592.174962
0.000198279	3618.490616



CALCULATION AREA

BEFORE CRACKING					AT CRACKING & YIELDING						BEYOND YIELDING					
Centroid (y)	Moment Of Inertia (uncracked)(I)	Distance b/w Centroid and Centre of Section (c')	Cracking Moment(Mcr)	Curvature (ϕ)	kd	I cracked	Cracking Moment(Mcr)	Curvature (ϕcr)	Moment (at yielding)	Curvature (ϕ)	β1	a	Centroid (Can)	Tensile Strain (es)	Ultimate Nominal Momen	Curvature (ϕ)
13.12	21870.22239	11.8780777	756.360652	1.1077E-05	7.465322283	8390.590201	756.3606525	2.88736E-05	3592.174962	0.000137129	.85	4.678	5.503	0.009	3618	0.000198279

Figure 9 Excel sheet for calculation of Moment-Curvature Curves

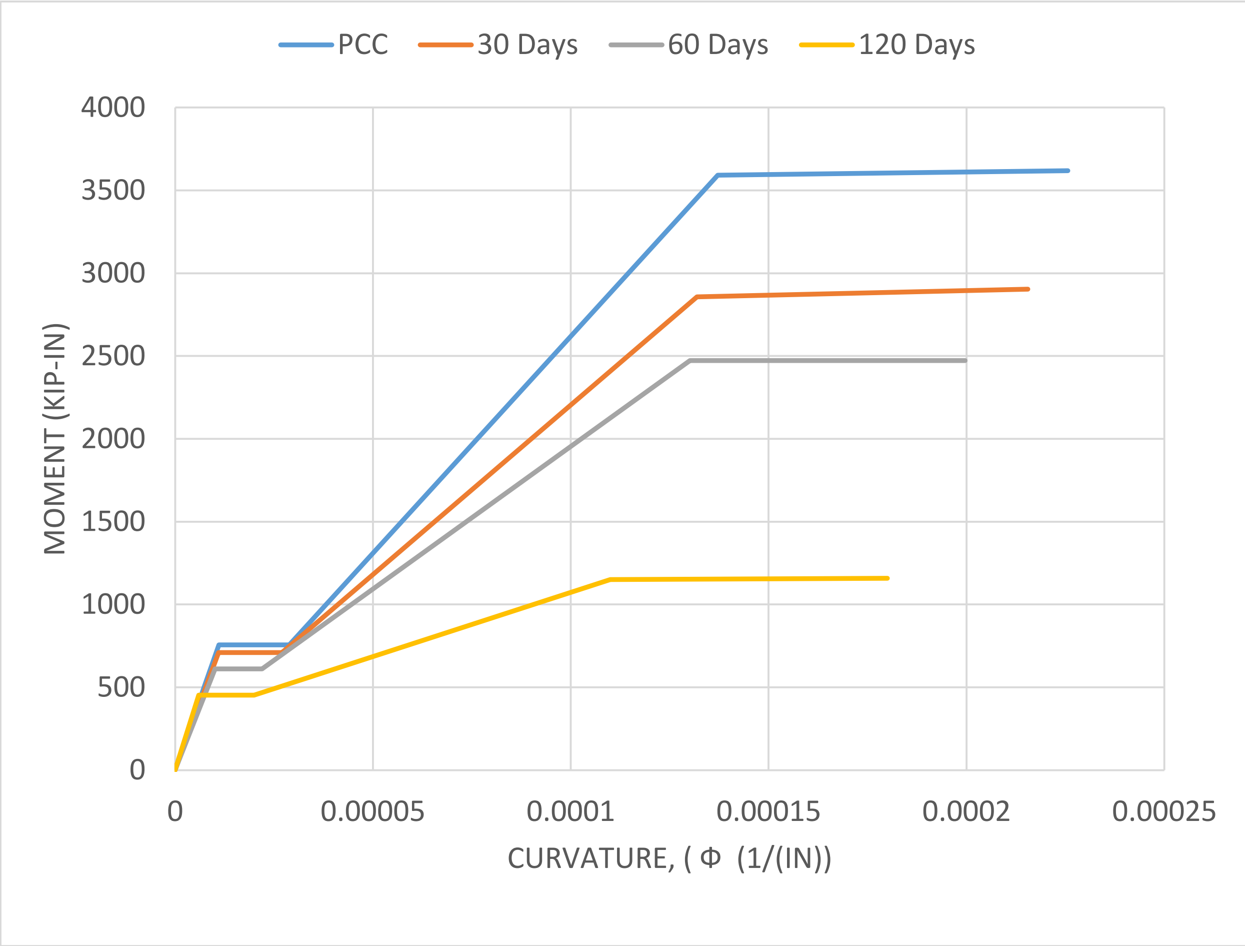


Figure 10 Moment-Curvature curves for 4 samples

Figure 10 shows an overlay of Moment Curvature graphs at 0, 30, 60 and 120 days. The graph clearly shows the decrease in strength parameters with exposure to sulphate attack in terms of Moment and Curvature. There are five points of inflexion in Moment-Curvature graph i.e. A, B, C, D and E. It is evident from the Figure 10 that as you move from the PCC line i.e. the blue line to 120 days of exposure to sulphate attack line i.e. Yellow line, Moment and curvature value on each points of B, C, D and E decreases but not in a linear way. You cannot say that for this much decrease in input parameters as discussed above this much reduction is expected because it is dependent on lot of factors and conditions.

3.5 Energy Absorption Capacity:

Area under the Moment-curvature graphs can be used to calculate the energy absorption of the structure i.e. the capability of a structure to successfully dissipate energy when it is subjected to seismic excitation. The area under the curve was calculated from Microsoft Excel employing a definite integral. Our base model has an area of 8723.7 square units and this area keeps on decreasing with exposure to more and more sulphate attack. Let's say our base model will have 100% energy absorption capacity then using that as a reference we calculated the capacity of each structure at various stages of sulphate attack and as area under the decreases so does the capacity of a structure to efficiently dissipate energy so a RC Frame structure at 120 days of exposure will only have a 36.85% energy absorption capacity which is very less. Even without running any analysis it is pretty obvious that this structure is very much likely to collapse if an Earthquake of 6+ magnitude hits.

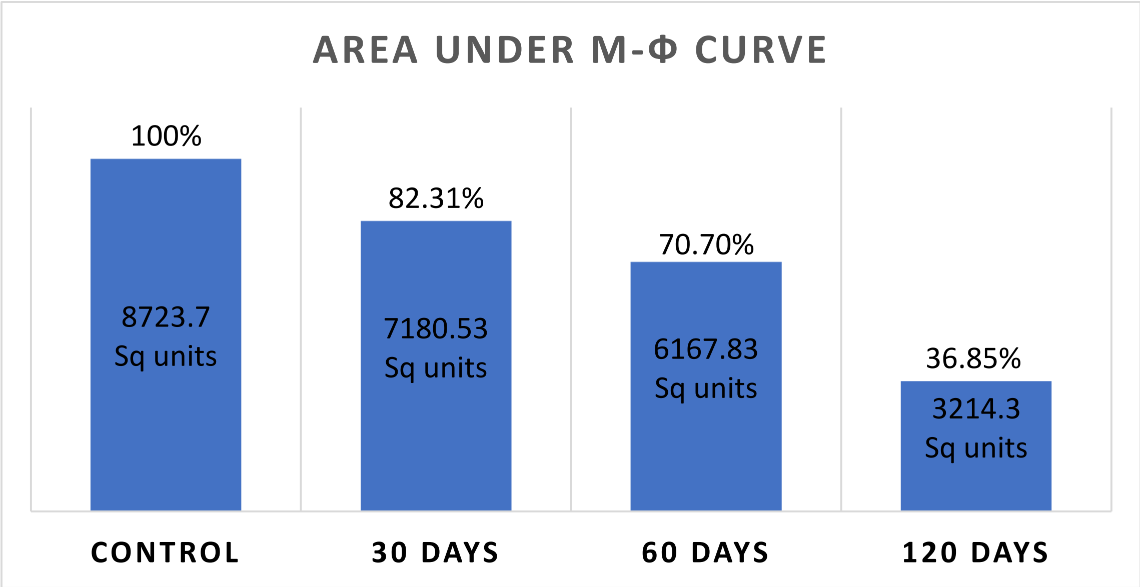


Figure 11 Area under Moment-Curvature Curves for 4 samples

4. Structural Modeling and Analysis

4.1 Selection of Building:

We have selected a 3 storey building for our analysis because it represents the most common footprint of multi-storey buildings in Islamabad as well as in Pakistan.

Figure 12 & 13 show an elevation and a 3-D view of our 3-storey building. A symmetrical building was selected so that it will have same deformation in both x and y direction. The building is a 3-Storey RC Frame structure with a height storey of 10.5 feet. The overall plan is 59x59 square feet. All beams are 15"x25" and all columns are 15"x15".

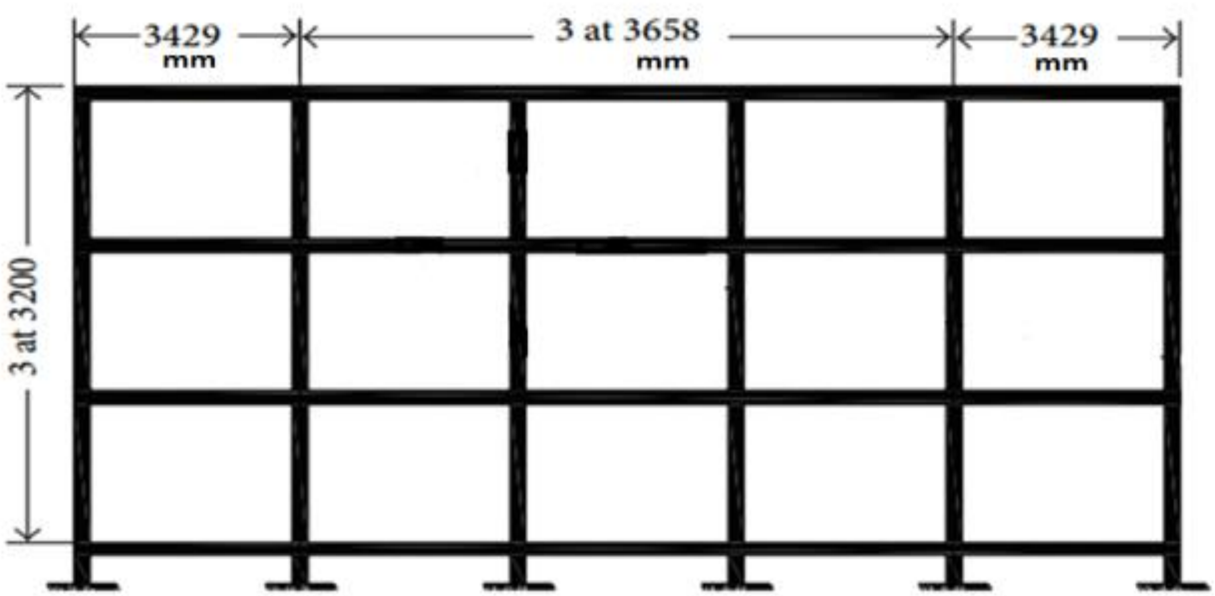


Figure 12 Elevation of Selected Frame

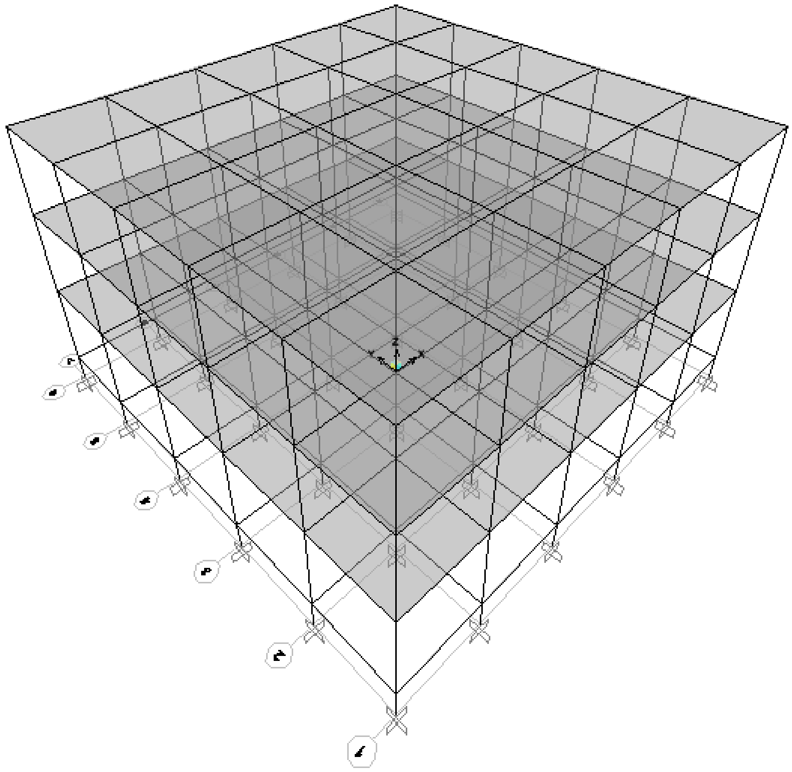


Figure 13 3D View of RC Frame

4.1.1 Building Characteristics:

The same building characteristics were used for all four models

Size of Model	59'x59' (3423 ft^2)
Storey Height	10.50'
No. of Bays in X-Direction	5
No. of Bays in Y-Direction	5
Beam Size	15"x25"
Column Size	15"x15"
Slab Load	D.L =40 lb/ft L.L= 60 lb/ft
Reinforcement	#9 main bars, #3 stirrups
Cover	1.5"

4.2 Gravity Analysis:

Gravity analysis analyzes the structure only on the basis of gravity loads i.e. the building must be safe within allowable limits under gravity loading.

Gravity load includes the dead load of the structure, human and snow load imposed on the structure. All these loads have a load transfer path to the ground. Various types of structural members are responsible for transferring this load to the sub-structure by supporting itself and the previous members.

4.2.1 Development of basic Model:

We selected SAP2000 for modeling and analysis. The 3d model of a 3-storey RC frame structure was built by following undermentioned steps:

i. First grids were defined by assigning positions and providing spacing in X, Y and Z direction according to our own model.
ii. The next step was to define materials, our base model was designed with a concrete of 3000 psi and steel reinforcement of 60000 psi.
iii. Next step was to define beams and columns which were defined arbitrarily (checked later on) under option of rectangular frame sections using default section properties and modification factors. The concrete reinforcements were added which were to be checked later on and therefore reinforcement to be designed option was marked. For this purpose #9 main reinforcement bars were provided and #3 transverse bars were provided. The cover for the main bars were 1.5" and longitudinal spacing given was 6".

iv. We defined the area section i.e. slab. The slab was designed as thin shell with a thickness of 6” at default values.

v. We assigned D.L of 40& and L.L of 60 pound per square feet to ours 3-D model and assigned the load combination of 1.2X(D.L)+1.6X(L.L)

4.3 Pushover Analysis:

4.3.1 Inelastic Methods of Analysis:

Structures behave in-elastically when subjected to seismic excitation so for accurate results inelastic analytical procedures should be exercised. They accurately depict the actual and real time behavior of structures by identifying modes of failure and the potential for progressive collapse. These procedures employ time history and pushover analysis. The Inelastic time history analysis gives most accurate results but is limited and impractical for seismic performance evaluation because of following reasons:

i. Sensitivity of characteristics of ground motion to dynamic response.
ii. Require proper modeling of characteristics of cyclic load deformation
iii. Require input in the form of sets of representative ground motion records.
iv. Also it takes a lot of computation and analysis time.

Due to above mentioned reasons, for the purpose of seismic performance evaluation we used pushover analysis as it is simple, less time consuming and requires no complex set of inputs from the user.

4.3.2 Description of Pushover Analysis:

Pushover analysis is a static nonlinear analysis method in which the structure is first subjected to gravity loading and then a monotonic displacement controlled lateral load pattern which continuously increases through elastic and in-elastic behavior until an ultimate condition is reached

4.3.4 Pushover Analysis Using SAP2000:

In our study we have done displacement controlled Pushover Analysis regardless of its limitations because it was easy to perform and interpretation of results was simple.

We have performed the Pushover Analysis of our building model in the following way:

- Analysis of our Base Model with control material properties.
- Analysis of 3 Modified Models with modified materials properties and user-defined hinges at 30, 60 and 120 days of exposure to sulphuric acid.
- Backbone curve comparison of base and modified model

4.3.5 Input Parameters for Pushover Analysis:

We have modeled 4 different models in sap 2000 having the same building characteristics but different material properties as shown in Figure 14.

These values were obtained from **σ-ε** curves of concrete and steel at various stages of sulphate attack as shown in Figure 14.

The next step was the hinge assignment. M2M3 hinge was assigned to beams and P-M2-M3 hinge to columns

Model	fc (psi)	fy (psi)	Ec (Ksi)	Ey (Ksi)
Control	3000	60000	3122	28986
30 Days	2818	47254	3026	22828
60 Days	2090	40888	2606	19753
120 Days	1296	18598	2052	8985

Figure 14 Material Properties of 4 models

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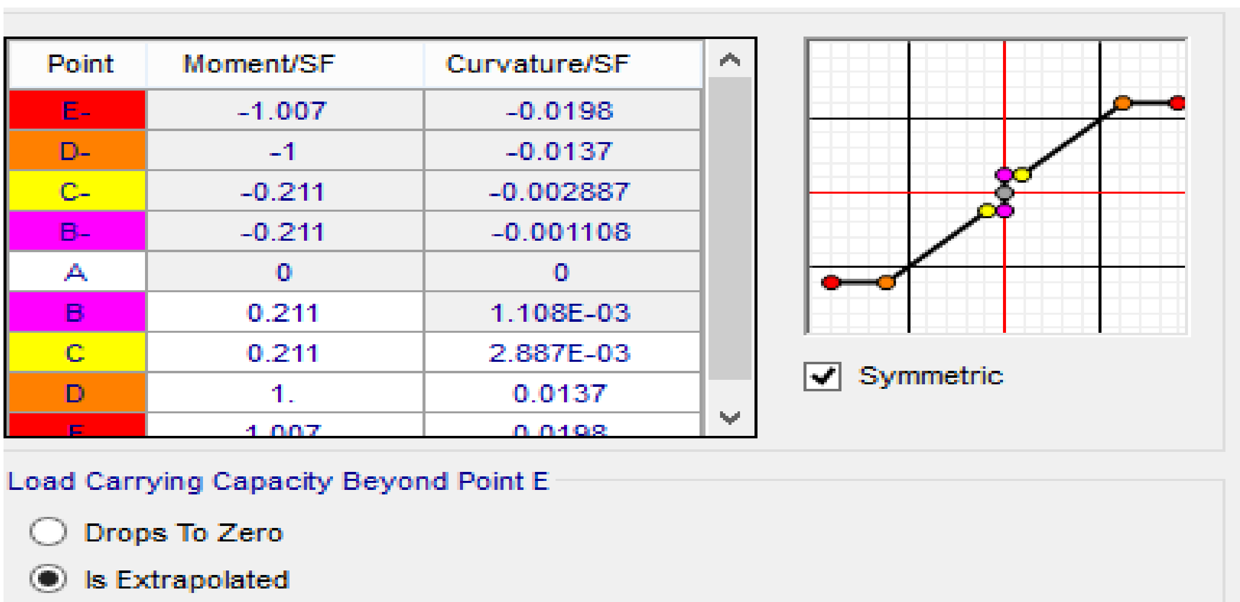
We have defined default hinges according to ASCE 41_13 at the both ends (i.e. at relative distance 0 and 1) in columns. For beams we use defined hinge Properties based on Moment-Curvature Graphs made from Whitney Stress block equations as explained in Experimentation phase. For each model user-defined hinge properties were used. Figure 16 shows the behavior of a particular hinge. We modified the plastic hinge properties by inputting the moment curvature curve values in displacement controlled parameters and Figure 15 shows user-defined hinge for our base model in sap 2000 which was defined in accordance to Figure 16 and Moment-Curvature Graphs.



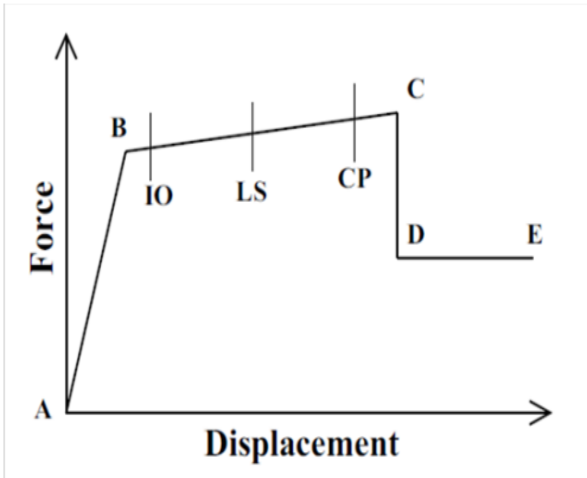
Point	Moment/SF	Curvature/SF
E-	-1.007	-0.0198
D-	-1	-0.0137
C-	-0.211	-0.002887
B-	-0.211	-0.001108
A	0	0
B	0.211	1.108E-03
C	0.211	2.887E-03
D	1.	0.0137
E	1.007	0.0198

Figure 15 User Define Hinge

Push over analysis require the formation of force-deformation curve for critical Sections of beams and columns (Figure 16) by using the following guidance:

Level	Description
Operational	Very light damage, no permanent drift, structure retains original strength and stiffness, all systems are normal
Immediate Occupancy	Light damage, no permanent drift, structure retains original strength and stiffness, elevator can be restarted, Fire protection operable
Life Safety	Moderate damage, some permanent drift, some residual strength and stiffness left in all stories, damage to partition, building may be beyond economical repair
Collapse Prevention	Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, building is near collapse

Point A corresponds to the unloaded condition. Load deformation relation shall be described by the linear response from A to an effective yield B. Then the stiffness reduces from point B to C. Point C has a resistance equal to the nominal strength then a sudden decrease in lateral load resistance to point D, the response at reduced resistance to E, final loss of resistance. The slope of the BC line is usually taken between 0and 10% of the initial slope. The CD line corresponds to an initial failure of the member. The DE Line represents the residual strength of the member. These points are specified according to FEMA to determine hinge rotation behavior of RC members. The points between B and C represent acceptance criteria for the hinge, which is Immediate Occupancy (IO), LS (Life Safety), and CP (Collapse Prevention).



Force - Displacement curve of a Hinge.

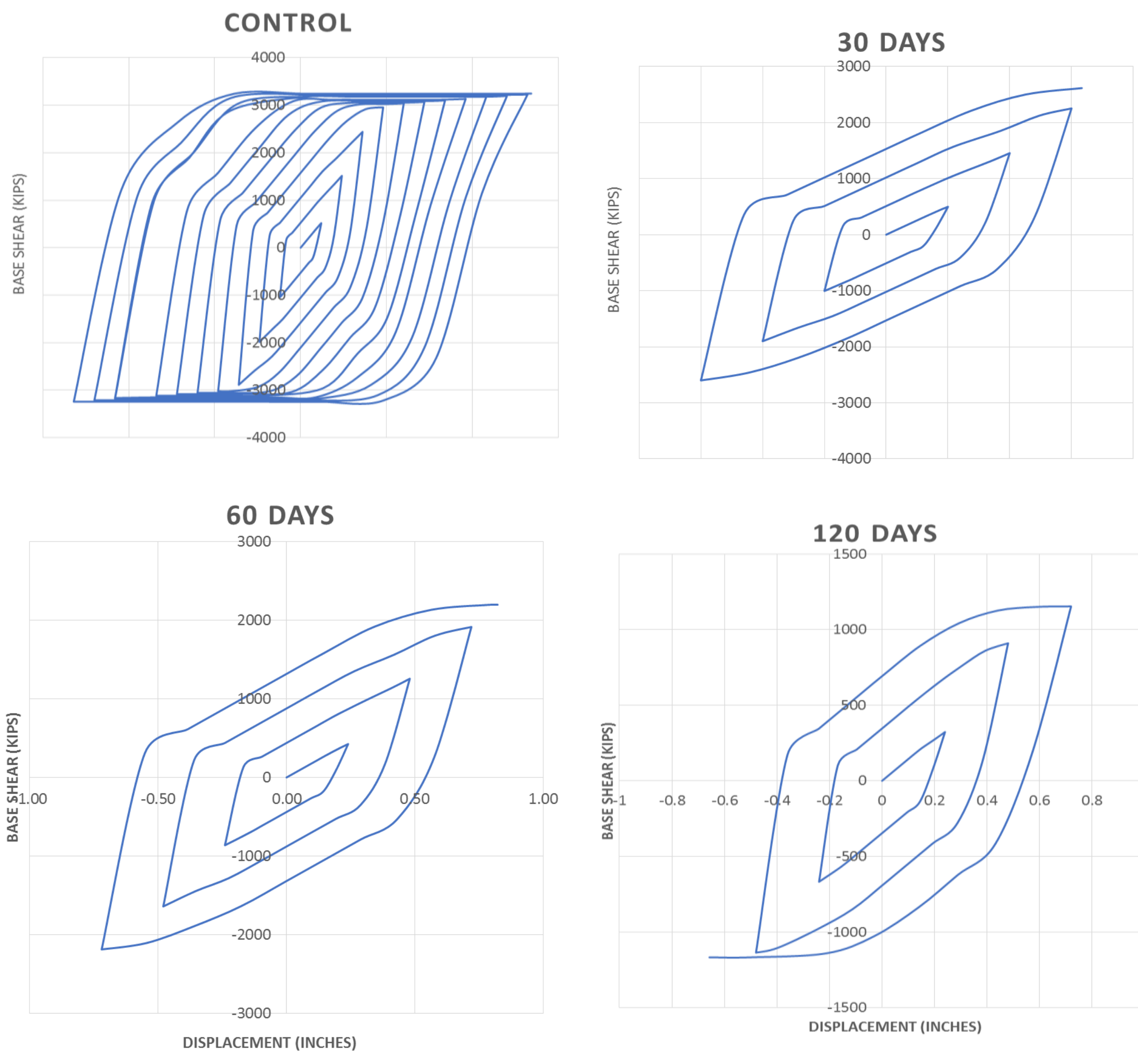
Figure 16 Behavior of hinge

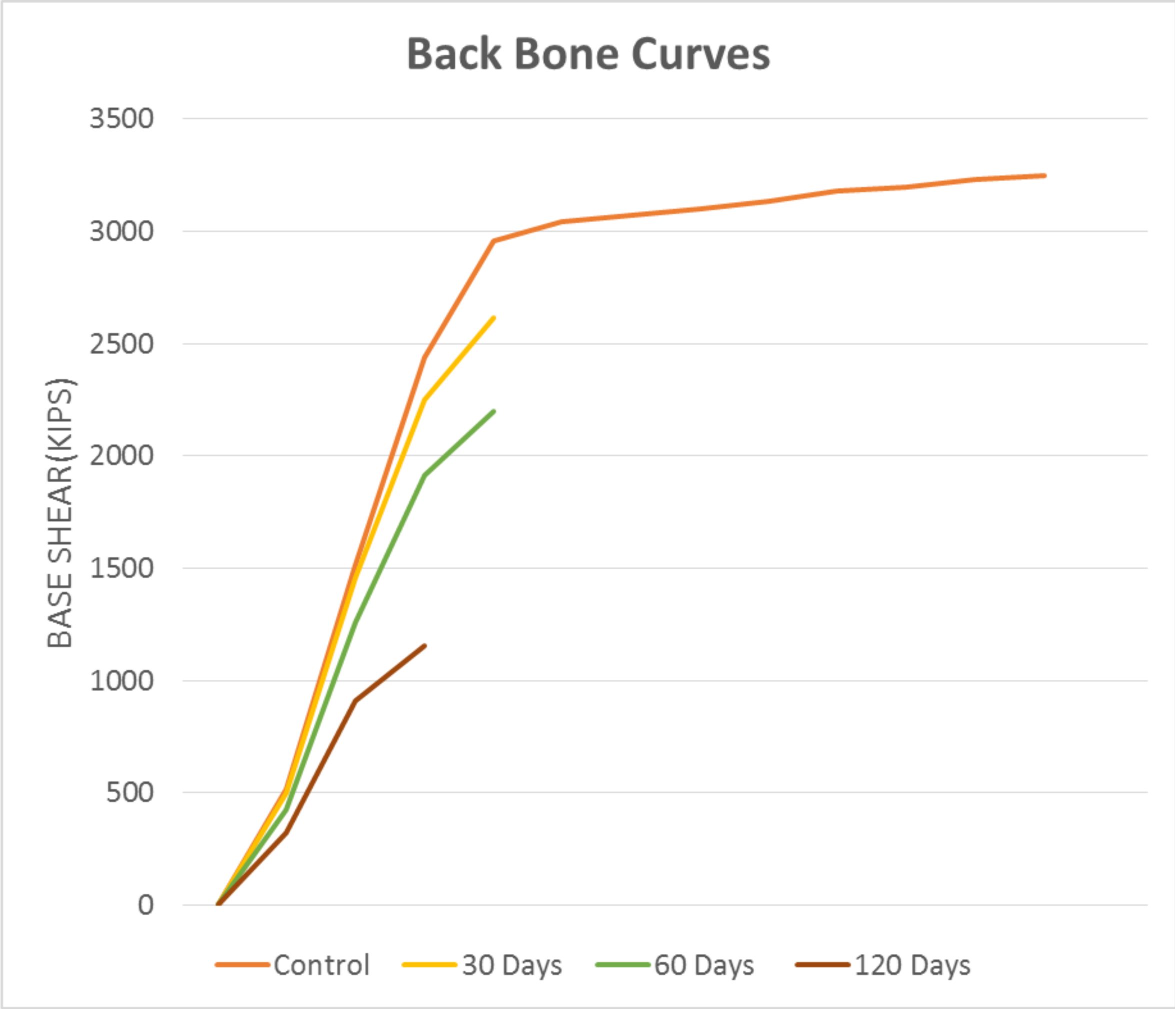
The user-defined hinges in beams and default hinges in columns are then overwritten by using hinge over write command.

Total of 4 pushover analysis were carried out using the same procedure .For each analysis hysteresis loops was obtained. The base model's hysteresis loop was compared with the modified models and back bone curves were established using the peak base shear and displacement values for each hysteresis loop.

5. Results and Discussion:

Hysteresis loops obtained for the base model and the modified models at 30, 60 and 120 days of sulphate attack were used to make the backbone curves by joining the peaks and then comparison was done to study the change in base shear of the 3-storey building as it experiences more and more deterioration due to sulphate attack. Figure 17 shows an overlay of back bone curves of all 4 models at various stages of sulphate attack





As seen in hysteresis loops our control RC Frame structure had base shear of 3245 kips and had gone up to large no of loading and unloading cycles before failing but as we progress to later stages due to decrease in fc & fy of rebar and also in Moment and curvature values in defined hinge our 3-storey RC frame structure's base shear gets reduced by 19.5% after 30 days, 32.3% after 60 days and a decrease of 64.5% after 120 days was observed. Also the consistent cycles of loading and unloading also decreases as evident from above figures.

Figure17 Back-Bone Curves of 4 Samples

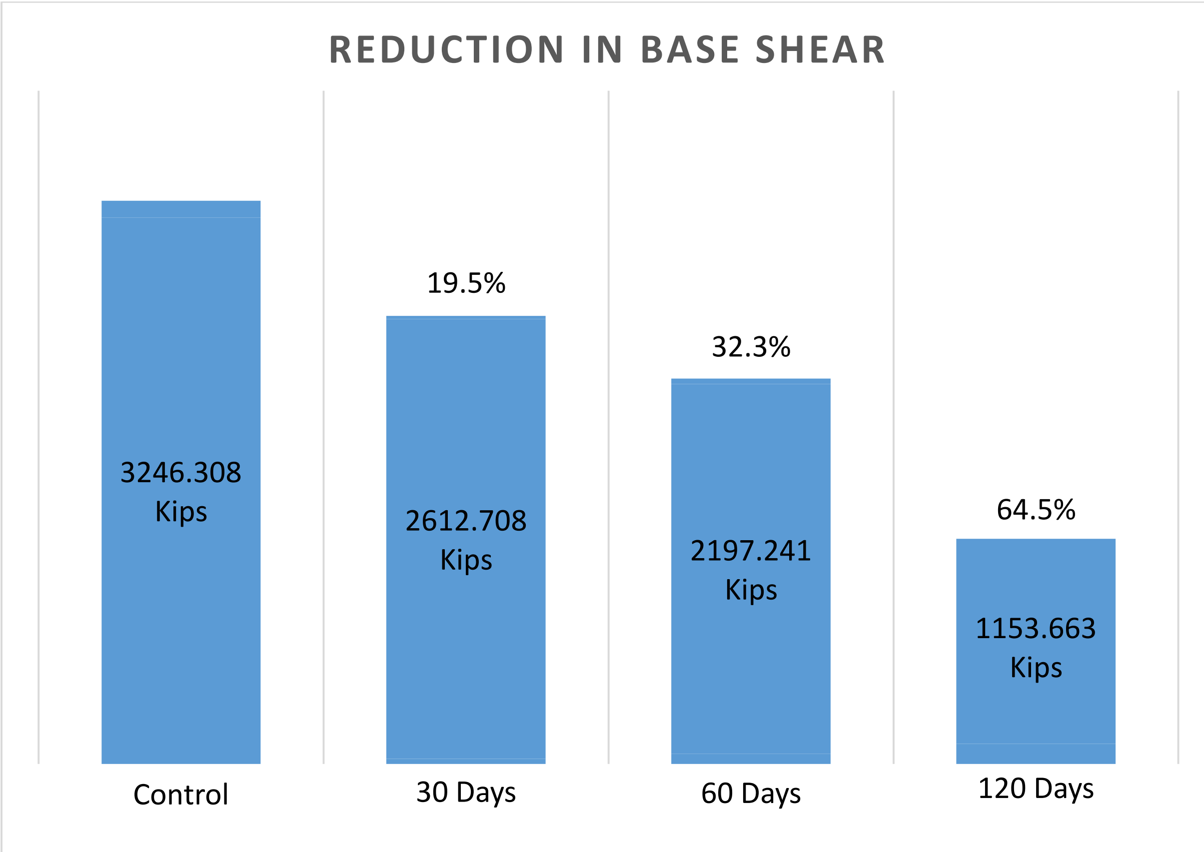


Figure 18 Reduction in Base Shear of 4 samples

Figure 18 clearly shows the relative and quantitative decrease in base shear as sulphate attack progresses. The bar chart values are extracted from the back bone curves of hysteresis loops obtained after each individual push over analysis at 4 Reinforced Concrete Frame structures. Reinforced Concrete Frame structure of base material properties of 3000 psi of concrete and 60000 psi of steel has a base shear value of 3246.3 kips which quite satisfactory. The RC frame structure at this stage has sufficient base shear and Energy absorption capacity as discussed earlier to resist significant seismic loading. Now the effect of sulphate attack on overall seismic performance of building is very drastic and it is clearly indicated by the fact that there is a decrease of 64.5% in the base shear of 120 days structure and RC frame structure at this stage has a base shear value of only 1154 kips which is very low.

6. Conclusions:

- We observe a 56.8% decrease in fc of concrete & 69% decrease in fy of Rebar
- With the decrease in compressive and Yielding strength we observe 63.15% reduction in energy absorption capacity & 65% reduction in Base shear of the Reinforced Concrete Frame
- From results obtained from experimental phase and also from Statistical Analysis phase from Sap 2000 using push over analysis as mentioned above, it is concluded that sulphate attack in fact compromise the ability of a RC Frame to behave efficiently under Seismic excitation.
- Due to the decrease in parameter values i.e. base shear, energy absorption capacity, compressive strength, yielding strength, permissible roof displacement, the RC Structure is more vulnerable to undergo major damage under Seismic activity in case of an Earth quake or even in case of application of high lateral loads in the form of wind.

7. Recommendations:

- Next step in this research will be retrofitting using Fiber Reinforced Polymer (FRP) or Carbon Fiber Reinforced Polymer (CFRP)
- This research has successfully established a base line by quantifying material properties of Reinforced Concrete Frame Structure at 0, 30, 60 and 120 days of exposure to sulphate attack.
- Now after making the sulphate medium with same concentration and molarity and casting RCC cylinders with same compressive strength and mix design. The samples should then be wrapped with appropriate retrofitting material and then immersed in the sulphate medium to see how effectively a retrofitting material behaves under sulphate attack.
- You can also see the performance of retrofitting material by first exposing Concrete cylinder to sulphate attack say for 30 days and then wrap it up and perform compressive strength tests. After testing and comparing values with our sample at 30 days you can have an idea of how much strength can be increased.
- Similarly a comparison of different retrofitting materials can be made to find out which is best suited to counter or increase strength in case of exposure to sulphate attack.

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