International Journal of Trend in Research and Development, Volume 3(4), ISSN: 2394-9333
www.ijtrd.com

Parametric Study of the Effect of Base Isolation on Performance of Structures

[1]Rashmi Guptha, [2]Dr. G. S. Manjunatha and [3]Dr. K. G. Guptha,
[1]PG Student (Structural Engineering), [2,3]Professor and Head of Department,
[1,2]Department of Civil Engineering, KLS Gogte Institute of Technology, Belagavi, Karnataka, India
[3]Department of Civil Engineering, Goa College of Engineering, Farmagudi, Ponda, Goa, India

***Abstract*—** Earthquakes are natural calamities that are characterized of releasing large amount of energy in the form of vibrations that damage structures. Base Isolation techniques help in decoupling the structure from its foundation thereby improving its performance. This article aims to study the response of G+3, G+10 and G+20 building models with different types of isolators (Lead rubber bearing and Friction Pendulum bearing) in respect of base shear, inter-storey drift, inter-storey displacements, frequency and time period when analyzed by different philosophies of analysis procedures (Equivalent Static Force Procedure[EQS], Response Spectrum Analysis [RS] and Time History Analysis [TH]). The results of the parametric study were compiled and discussed in an effort to draw conclusions so as to be able to suggest the type of isolation to be adopted.

Keywords*—Friction Pendulum Bearings, Inter-Storey Drifts, Inter-Storey Displacements, Lead Rubber Bearings*

I. INTRODUCTION

Base isolation is a technique that has been developed and extensively adopted especially in severe seismic zones to protect structures against damaging effects of ground shaking. Action of base isolators is analogous to the action of suspension springs provided in a car. The ultimate aim of the isolators lies in absorbing ground vibrations, thereby minimizing their transmission to the superstructure above during an earthquake and increases the period so as to attract lesser seismic forces [1]. This technique can be very well adopted for medium to high-rise structures made of brick, stone or reinforced cement concrete (RCC). The base isolation techniques are also very efficient as retrofitting measures for already existing structures.

A. Lead Rubber Bearings

Elastomeric bearings are the most preferred type of isolators which find their application in wide spectrum of Civil Engineering structures. The desirable engineering characteristics of elastomeric bearings include: high vertical load carrying capacity, rotational capacity, translational movement in any horizontal direction and minimum effects of seating distortions or span deformations apart from being economical [2]. The bearing consists of alternate layers of steel shims and rubber which may be natural or neoprene rubber bonded together to form a single integrated unit. This unit as a whole decouples the superstructure from the horizontal component of earthquake ground motion thus introducing a flexible layer between the structure and its foundation [3]. The bearing has high vertical stiffness, which is slightly improved by introducing a lead plug at the central axis. Vertical stiffness ensures that there are no settlements or sandwiching of the layers due to weight of the superstructure. Horizontal flexibility allows small lateral movement thus reducing the effects of destructive horizontal vibrations [4].

B. Friction Pendulum Bearings

Friction pendulum bearings work on the principle of a simple pendulum. It essentially consists of a slider that moves along a concave surface when subjected to lateral vibrations during the event of an earthquake. The dimensions of the isolator are fixed up based on the size of structure being supported, type of soil in the locality, load capacity requirements and earthquake displacement capacity. When the structure is subjected to lateral vibrations, the sliding arrangement provided helps in absorbing the energy which is spent in the work done to overcome the friction and slide along the concave inner surface. This indirectly reduces the acceleration imparted to the structure as the period of the isolated structure gets lengthened. This type of isolator has the capacity to re-center itself and the structure even after it undergoes displacement from its equilibrium position due to gravity force and the concave inner surface [5].

II. MODELLING

The multi storey structure considered for carrying out the proposed parametric study was modelled as a bare frame with only beams and columns, having a plan area of 560 square meters, with four bays of 5m each in the X direction and four bays each of 7m in the Y direction when viewed from top. Building frames with G+3, G+10 and G+20 floors were considered for the parametric study. Storey height and slab thickness have been taken as 3 mt and 0.1mt respectively. The connections between beams and columns were assumed to be rigid. Tables 1 to 3 present modelling details considered for analysis in MIDAS Gen while tables 4 and 5 present the design details of Lead Rubber Bearing and Friction Pendulum Bearing respectively. Figures 1 and 2 depict the chosen time history and plan of the building models respectively.

Table 1: Material Properties as Defined in MIDAS Gen

No.	Parameter	Value
1	Grade of concrete	M30 for G+3 M40for G+10 and G+20
2	Design Code	IS(RC) 456:2000
3	Modulus of elasticity	2.7386e+007 KN/m^2
4	Poisson’s ratio	0.2
5	Thermal Coefficient	5.5556e-006 per deg F
6	Weight Density	23.6KN/m^3
7	Damping ratio	0.05
8	Type of infill	FRI bricks
9	Modulus of elasticity	1.4000e+007 KN/m^2
10	Poisson’s ratio	0.213
11	Thermal Coefficient	8.6360e-008 per deg F
12	Weight Density	17.61 KN/m^3
13	Thickness of masonry infill	230mm

Table 2: Parameters for Carrying-out Seismic Analysis

No.	Parameter	Value
1	IS Code adopted for design	IS 1893(2002)
2	Seismic zone	III
3	Zone factor	0.16
4	Type of soil	Hard rock
5	Importance Factor	1
6	Percentage Damping	5%
7	Fundamental period in x direction	0.3897 sec
8	Fundamental period in y direction	0.3897 sec
9	Response Reduction Factor	5

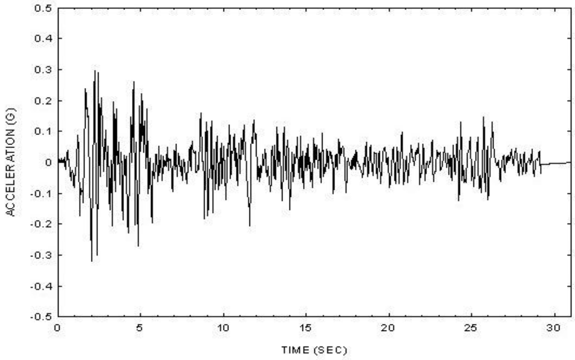


Figure 1: Time History of May 18, 1940 El Centro Earthquake

Table 3: Loads and Modeling details for the Structure

No	Type of load	Magnitude of load
1	Self weight	Assigned in negative z direction
2	Wall load on floor beams	15.75KN/m
3	Wall load on roof beams due to parapet 1m high	6.08 KN/m
4	Wall load on roof beams during earthquake analysis	8 KN/m
5	Live load of floor	4.5 KN/m^2
6	Floor finish of floor	1.5 KN/m^2
7	Load due to slab	3.54 KN/m^2
8	Live load on roof during earthquake analysis	0 KN/m^2
9	Dead load of roof	3KN/m^2
10	Percentage of live load considered during earthquake analysis	25%
11	Type of eigen value analysis adopted	Lanczos with 12 iterations
12	Time history	El centro
13	Type of time history analysis	Linear
14	Analysis method	Modal
15	Type of time history	Transient
16	Damping method	Modal
17	Time function data type	Normalized acceleration

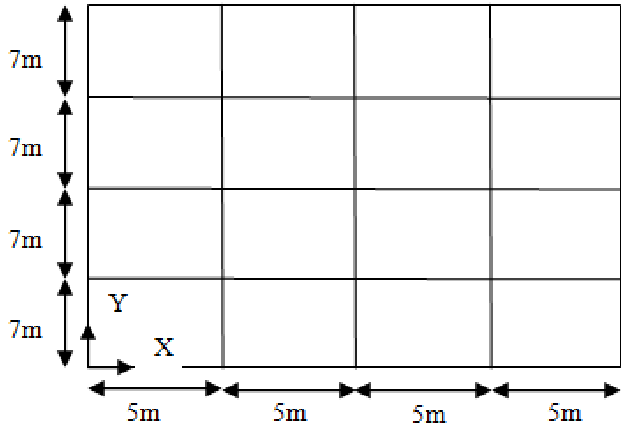


Figure 2: Typical Plan of G+3, G+10 and G+20 Building Models

III. RESULTS

All the models (G+3, G+10 and G+20) were analysed employing "MIDAS General" software for the following conditions depending on whether the base is fixed or isolated and the type of isolation technique adopted:

1. Fixed base, to restrain displacement and rotation.
2. Base isolated with lead rubber bearings, allowing lateral displacement with sufficient vertical stiffness (designed for the maximum value of support reaction under service loads) [7]. Lead rubber bearings are considered for hard , medium and soft soils with the following notations :
   a. LRBH :Lead Rubber Bearing for Hard soils
   b. LRBM : Lead Rubber Bearing for Medium soils
   c. LRBS : Lead Rubber Bearing for Soft soils
3. Base isolated with friction pendulum bearings, allowing lateral displacement within the concave spherical plate with designed radius and co-efficient of friction. The horizontal and vertical stiffness of the bearings were designed based on the total load of superstructure and substructure [6].

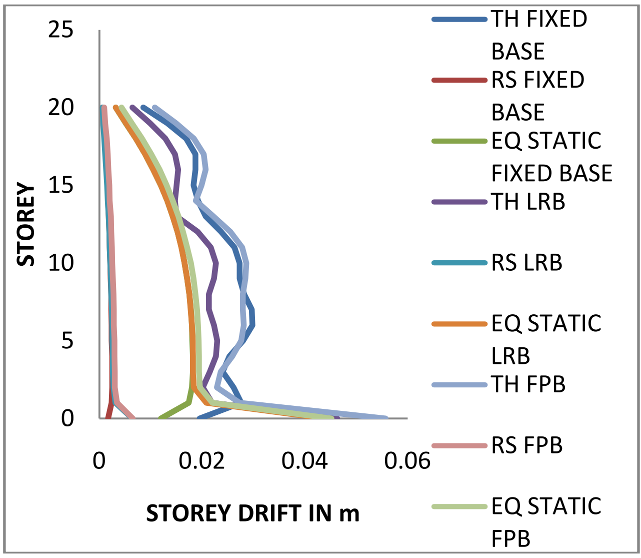
The storey drift, its displacement, natural period and base shear of the models were evaluated for all the above conditions using the following analysis philosophies:

a. Equivalent Static Force Procedure (Static analysis procedure)
b. Response Spectrum Analysis and (Dynamic analysis procedure)
c. Time History Analysis (Dynamic analysis procedure)

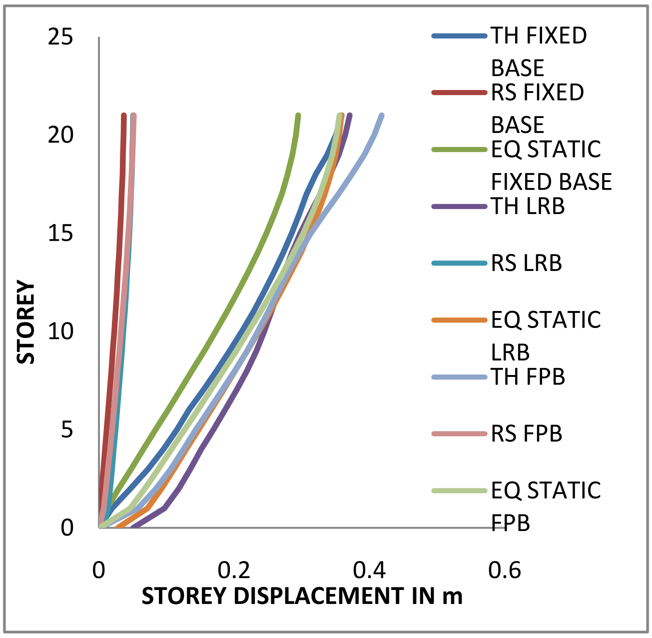
Considering critical combinations of the parameters, for the particular type of isolation, the inter-relationship existing between

a. Storey level and storey drift
b. Storey level and storey displacement
c. Variation of base shear
d. Period and mode number
e. Frequency and mode number

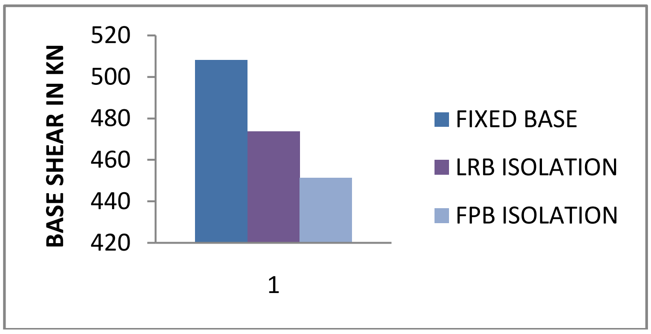
are evaluated and discussed.



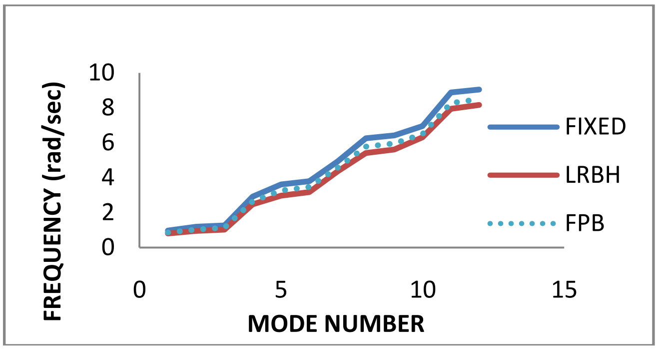
Graph 01: Variation of Storey Drift for Different Types of Isolation techniques and Analysis Procedures.



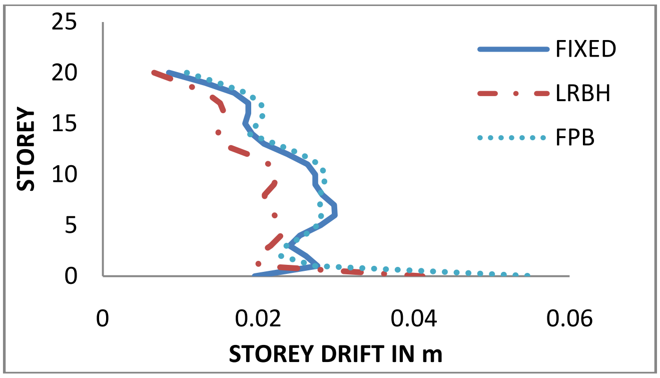
Graph 02: Variation of Storey Displacement for Different Types of Isolation techniques and Analysis Procedures.



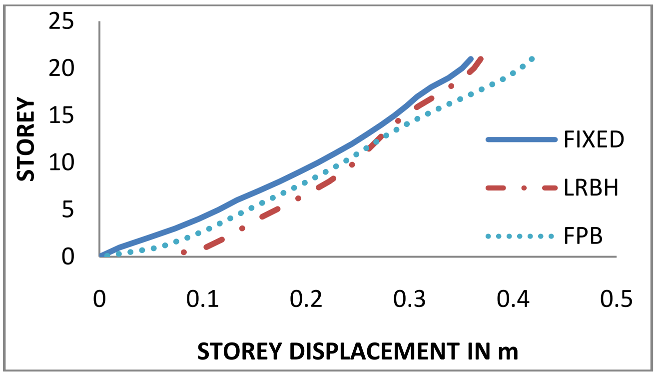
Graph 03: Variation of Base Shear for Different Types of Isolation techniques.



Graph 04: Variation of Frequency of the Structure for Different Types of Isolation techniques.



Graph 05: Variation of Storey Drift under Time History Analysis for Different Types of Isolation techniques.



Graph 06: Variation of Storey Displacement under Time History Analysis for Different Types of Isolation Techniques

Graphs 1, 2, 3 and 4 show the inter storey drifts, displacements, base shear and frequency of the structure respectively for (G+20) RCC building considering different methods of analysis and different types of isolators. Graphs 5 and 6 show variation of inter storey drift and displacement for twenty storeyed RCC building considering different types of isolation technique for time history of 1940 El Centro Earthquake.

Base isolation of the structure increases its time period thereby improving its performance. An increase in period refers to a corresponding decrease in the frequency of the structure since these two parameters are inversely proportional. This fact is well depicted in graph 4. Since the frames with fixed base has the least period, it has maximum frequency, followed by buildings isolated by FPB and LRB techniques.

Isolating a structure also results in reducing the base shear to which the structure would be subjected to otherwise. Isolators at the base tend to absorb the seismic vibrations which allow its lateral deformation. Thus the absorbed energy is used up in allowing the isolator to deform laterally. Only small amount of vibrations are transferred to the structure. This behaviour of the isolator reduces the base shear remarkably which is very well depicted in graph 3. Vibrations go unabsorbed in fixed base case due to which it is subjected to maximum base shear. LRB and FPB isolators absorb the seismic energy thereby lowering the base shears on the structure.

Introduction of isolators to decouple the base and the superstructure results in increasing the inter-storey displacements relative to the fixed base case on account of imparting flexibility to the structure as depicted in graph 2 irrespective of the method used for analysis. Inter-storey displacements are maximum at the base (relative to the fixed base case) for isolated cases due to the lateral deformation of isolators. Further, since the fixed base case has least flexibility and zero displacements at the base, graph 2 and 6 shows the variation to begin from the origin while for isolated cases, the variation begins for some finite amount of displacement accounting for deformation of the isolator. Further analysis shows that LRB resulted in smaller displacements than FPB type of isolation.

Graph 1 depicts the variation of inter-storey drift for different types of isolation cases. Graphs 1 and 5 show drifts to be greater for isolated cases at the base and reduce considerably at the top storeys relative to the fixed base case. A larger drift at the base is due to lateral deformation of the isolator. In general, LRB isolation results in relatively lower drifts as compared to FPB isolation at the base and also has performed better than FPB (by having drifts lesser than fixed base case).

The results of time history analysis and equivalent static force method of analysis are more or less in good agreement with each other. However, this statement is true when the necessary magnification or scaling up of the shear is not done (as in the present study). In the considered case response spectrum results are more reliable than other two methods. Though time history analysis gives more realistic results, in the present study El Centro earthquake has been considered and an earthquake similar to that of El Centro occurring in India is quite bleak. However, the reason for selecting El Centro time history is just to carry out the parametric study, which can be taken up for any other time history. On the other hand, results by response spectrum analysis are always more reliable for distribution of storey forces and storey shears than equivalent static force method of analysis. This is due to the fact that in response spectrum analysis, eigen value problem is solved to obtain period while equivalent static force method calculates period of the structure based on codal formula considering height and type of frame. Table 6 presents the variation of all the considered parameters for different types of method of analysis and type of isolation provided.

IV. DISCUSSION OF RESULTS AND CONCLUSIONS

1. Choice of selecting a particular type of isolation depends on assessing its overall performance in terms of drifts, displacements, shear and period. Engineer has to bear in mind all the physical and financial constraints together with its performance before selecting the type of isolation technique.
2. Base shear reduced considerably when the base is isolated using friction pendulum bearing and analysed using time history analysis but the reduction in base shear was found to be relatively lesser when analysed by equivalent static force procedure.
3. From the study, it was observed that the storey drift was relatively greater for isolated structure at the base but as the number of storeys increased the storey drifts in isolated buildings reduced in comparison with fixed base structure.
4. Base isolation reduced the inter storey drift but increased the storey displacement relative to fixed base structure due to the elasticity imparted by the isolation system.
5. Base isolation also enhanced the flexibility of the structure as a whole thus increasing the period of the structure and making it less susceptible to attract greater magnitude of lateral forces.
6. G+20 model showed 6.74% and 11.15% reduction in base shear for LRB and FPB isolated cases respectively, relative to fixed base frame when analyzed by response spectrum analysis.
7. Response spectrum analysis for G+20 model indicates 44.86% and 38.65% increase in top storey displacements for LRB and FPB isolated cases respectively relative to fixed base frame.
8. Response spectrum analysis for first mode for G+20 model also shows 18.73% and 12.53% increase in period for LRB and FPB isolated frames respectively, relative to fixed base frame

Pattern and trend of the considered parameters namely base shear, inter storey displacement, inter storey drift and natural period are similar to the results obtained by [7] and [4]

Table 4: Design Details of Lead Rubber Bearing Isolator

No.	Soil Type	Sa/g	K_h(KN/m)	K_v(KN/m)	Infill	Load	Floors
1	Hard	0.5	377	172862.7	Present	1546.3	G+3
2	Medium	0.68	525	310245	Present	1546.3	G+3
3	Soft	0.835	647	310245	Present	1546.3	G+3
4	Hard	0.5	332	138340	Absent	1371.5	G+3
5	Medium	0.68	463	249527	Absent	1371.5	G+3
6	Soft	0.835	570	353729	Absent	1371.5	G+3
7	Hard	0.5	1003	888494	Present	3957.9	G+10
8	Medium	0.68	1386	1452572	Present	3957.9	G+10
9	Soft	0.835	1703	1958260	Present	3957.9	G+10
10	Hard	0.5	1047	951213	Absent	4116.2	G+10
11	Medium	0.68	1442	1539896	Absent	4116.2	G+10

12	Soft	0.835	1777	2081468	Absent	4116.2	G+10
13	Hard	0.5	1982	2423763	Present	7684.2	G+20
14	Medium	0.68	2727	3732197	Present	7684.2	G+20
15	Soft	0.835	3356	4882090	Present	7684.2	G+20
16	Hard	0.5	1887	2264633	Absent	7309.5	G+20
17	Medium	0.68	2591	3487492	Absent	7309.5	G+20
18	Soft	0.835	3184	4563091	Absent	7309.5	G+20

Table 5: Design Details of Friction Pendulum Isolator

No.	**Max.vertical reaction**	**Radius of curvature**	**Coeff. of friction**	V_{bmax}	K_v	K_h	**Floors**	**Infill**
1	25948.12	2.235	0.1	0.15	28908.64	23126.915	3	Present
2	21052.9	2.235	0.1	0.15	23454.91	18763.927	3	Absent
3	33786.06	3.048	0.1	0.15	66435.48	53148.382	10	Present
4	65774.06	3.048	0.1	0.15	65428.79	52343.031	10	Absent
5	124558.83	3.962	0.1	0.15	114477.59	91582.074	20	Present
6	120426.35	3.962	0.1	0.15	110679.58	88543.661	20	Absent

Table 6: Comparative Results of Considered parameters for Different Types of Analysis Procedures and Type of Isolation

Parameter	**Response Spectrum Analysis**			**Equivalent Static Force Method**			**Time History Analysis**		
	FIXED	**LRB**	**FPB**	**FIXED**	**LRB**	**FPB**	**FIXED**	**LRB**	**FPB**
Displacement	0.037	0.0491	0.0513	0.169	0.2071	0.375	0.3588	0.3708	0.418
Peak Drift	0.0025	0.0064	0.0065	0.01	0.0222	0.04	0.0298	0.0411	0.0557
Period	6.5332	7.7568	7.352	6.5332	7.5	7.352	7.124	8.185	8.0198
Frequency	1.3847	1.2089	1.2318	0.9617	0.8377	0.8546	0.882	0.7676	0.7835

References

[1] Ashish R Akhare and Tejas R Wankhade, (2014), “Seismic Performance of RC Structure Using Different Base Isolator”, International Journal of Engineering Sciences and Research Technology Vol 3, Issue 5, pp 724-729.

[2] S.K.Sabu, H.S. Chore and S.B. Patil (2014) “Effectiveness of Lead Rubber Base Isolators for Seismic Resistance of Buildings Supported on Different Soil Stratas” International Journal of Electrical, Electronics and Computer Systems, Vol 2, Issue 4, pp 53-59.

[3] Animesh Das, Anjan Dutta and S K Deb (2012) “Modelling of Fiber Reinforced Elastomeric Base Isolators”, 15th World Conference on Earthquake Engineering,Lisboa, Portugal.

[4] P Warn, Andrew S Whittaker and Michale C Constantinou (2007). “Vertical Stiffness of Elastomeric and Lead –Rubber Seismic IsolationBearings” Journal of Structural Engineering, Vol,133 Issue 9 pp 1227-1236

[5] Nikolay Kravchuk, Ryan Colquhoun and Ali Porbaha, (2008), “Development of Friction Pendulum Bearing Base Isolation System for Earthquake Engineering Education”, Proceedings of 2008 American Society for Engineering Education Pacific Southwest Annual Conference.

[6] P.P.Diotallevi, L Landi and G.Grazi, (2014), “On the Seismic Analysis of Structures with Friction Pendulum Isolators Subjected to Horizontal and Vertical Ground Motions”, Tenth US National Conference on Earthquake Engineering, Alaska.

[7] Minal Ashok Somvanshi and Rina N Pantawane, (2015), “Seismic Analysis of Fixed Base andBase Isolated Building Structures”, International Journal of Multi Disciplinary and Current Research, Vol 03, July-August 2015 Issue, pp 747-757

Rashmi Guptha: She was born on 20th Jan 1993 in Hyderabad. She completed her Bachelors degree in Civil Engineering at KLS Gogte Institute of Technology, Belagavi (2014) and is presently pursuing her Masters in Structural Engineering at KLS Gogte Institute of Technology, Belagavi. Areas of interest include Structural Dynamics and Earthquake Engineering.

Dr. G. S. Manjunatha : Completed his B.E. (Civil Engg.) from University Vishveshvaraiah College of Engineering, Bangalore in 1985 and M.E.(Structural Engg.) from KLS Gogte Institute of Technology, Belagavi in 1989. He was awarded Ph.D. by Visvesvaraya Technological University, Belagavi in 2013. His areas of interest include Structural Engineering, Concrete Technology and Geopolymer Technology. He served as Special Officer, Visvesvaraya Technological University, Belagavi and Coordinator, IGNOU Study Centre, GIT Campus, Belagavi. Currently, he is heading the Department of Civil Engineering, KLS Gogte Institute of Technology, Belagavi.

Dr. K G Guptha: Professor and Head of Civil Engg. Dept at Goa College of Engg. Farmagudi. Having 30 years of experience, published 15 Papers, has a Patent; Two are working for Ph.D and member of several professional bodies. Areas of interest include Concrete Technology and Environmental Engineering.