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Analytical Study on Seismic Stability of Different Foundation Connection

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Abstract— *Precast concrete structures are used globally nowadays because it shorten construction period, improves productivity, cost efficiency, and superior plant control of structural elements with conventional cast-in situ concrete structures. The column – footing connection is a main function in almost every kind of structure, because it transfers load of the structure to the footing. Hence this study has been made on Seismic Analysis of precast concrete column to the foundation connection. In this study different types of existing connections between the concrete column and foundation was clearly explained and the force transferring mechanism from column to foundation was also described. Seismic behavior of pocket foundation connection, grouted sleeve connection and in-situ socket foundation connection are analysed and the results are compared. A Reinforced Concrete frame building was taken and analyzed with ETABS software against seismic forces, the resultant forces and moments in critical column to footing region and the base shear values are obtained. The results obtained from the ETABS were used for design and detailing of pocket foundation, grouted sleeve connection and in-situ socket foundation connection. The Finite element modeling for Pocket foundation connection, grouted sleeve connection and in-situ socket foundation connection has been created and analyzed with the ANSYS Package. The results are discussed.*

Keywords— *Precast columns, foundation connections, pocket foundation connection, grouted sleeve connections, in-situ socket foundation connection, seismic stability, ANSYS.*

I. INTRODUCTION

In Precast concrete constructions, connections are used for linking one precast module to another and also to connect precast components to the structural framework of cast-in-place concrete, steel, or masonry. The connections can be between column or wall to foundation, beam to column or wall to wall, slab to slab or structural steelwork, in-situ concrete, timber and masonry to precast concrete components. In order to perform this function, connections must able to transmit moments, shear, axial loads, and torsion. Connection design is one of the most significant considerations for the successful construction of precast reinforced concrete structures. This is for the reason that the structural performance of precast concrete systems depends on the behaviour of connection. The configuration of the connections affects the constructability, stability, strength, flexibility and residual forces in the structures. Finite element analysis (FEA) is a technique to simulate the loading condition on a design and verify the design's response to those circumstances. FEA is based on the idea of building a complicated object with simple blocks, or dividing a complicated object into small convenient pieces. There are different methods for fixing precast concrete columns to an in-situ foundation. Here three types of connections are chooses to carry out the analytical study using ANSYS software. 1) grouted sleeve connection 2) pocket foundation connection 3) in-situ socket foundation connection.

II. REVIEW OF LITERATURES

Fleischman et al. (2004) conducted study on "development of a seismic design methodology for precast Diaphragms" The precast concrete industry has mounted a sustained effort to develop seismic-resistant precast concrete construction for buildings, largely supported by Precast Seismic Structural Systems (PRESSS) program funded by the National Science Foundation.

Ehsan Noroozinejad Farsangi et al. (2010) carried out study on "Connections Behaviour in Precast Concrete Structures Due to Seismic Loading". This paper presents a finite element analysis on 4 types of precast connections which are pinned, rigid, semi rigid and a new proposed connection. The stiffness of the new connection is obtained from the slope of the total load versus deflection graph in the elastic range. Then the seismic loading from El Centro earthquake modified with 0.15g and 0.5g were applied to the whole structure. From the analysis results, new connection has sufficient stiffness, strength and also higher ductility. Meanwhile, the whole structure analysis results showed that the new connection behaves as semi rigid connection. LUSAS and SAP2000 have been used for analysis.

Paolo Riva et al. (2012) conducted study on the behavior and performance of grouted corrugated steel sleeve connections under cyclic loading. While the behavior of precast concrete socket base connections is well documented, 4–6 no published experimental results concerning the cyclic response of grouted sleeve column-to-foundation connections have been found.

III. METHODOLOGY

The methodology for the present investigation is as follows:

- Fixing the objectives
- Modeling of RC framed structure using ETABS software: Fixing the dimensions, support conditions, assigning properties and loads
- Analysis of structure using ETABS software
- Tabulating the results: critical load acting on the column, and horizontal reactions
- The pocket foundation is designed for the critical loading

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- Design and modeling the pocket foundation, In-situ socket foundation connections and grouted sleeve connection by using ANSYS software
- Meshing of models
- Analysis of the foundation connections
- Study the seismic response of the connections
- Comparing the seismic behavior of different connections
- Interpretation of results

IV. Modeling and Analysis of Structure

A. General Detail and Geometry

For the design of connections a G+2 storey building was modeled and analysed using ETABS software. The location of the building is assumed as kerala which is zone 2 category. The total height of the building is 9.2m and area is 112m^2. The seismic analysis was performed using equivalent lateral force method as given in IS: 1893-2002. The design and detailing of beam, column, slab and foundation was carried out based on the guidelines given by IS: 456-2000 and IS:13920-1993. The material characteristics are M30 grade of concrete and Fe 415 grade steel. All the supports are assumed as restrained against translation and rotation.

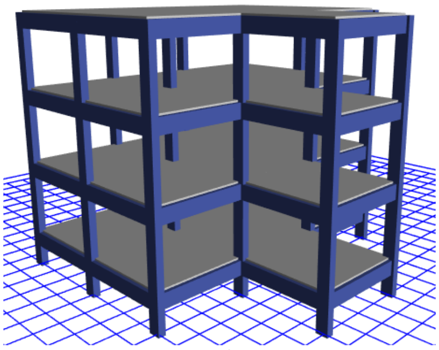

Fig. 1. Model of the structure.

TABLE I. Results obtained from ETABS software.

Critical load acting on the column (F_Z)	1388.6kN
Horizontal forces acting on the column (F_X)	-33.6kN
Horizontal forces acting on the column (F_Y)	40.26kN

Column and footing are designed according to the results from ETABS using IS456

B. Design of Pocket Foundation

For pocket connections, either cast- in-situ or precast type footings can be used. The insitu concrete foundation is cast using a tapered box shutter to form the pocket. The gap between the pocket and the column should be at least 75 mm at the top of the pocket. The basic precast column necessitate only additional links to resist bursting pressures generated by end bearing forces, and a chemical retarder is needed to expose the aggregate in the region of the pocket. If overturning moments are there, half of the skin friction is conservatively disregarded due to probable cracking in all of the faces of the precast/ insitu periphery. The Ultimate load design considers vertical load transfer by end bearing based on the potency of the gross cross-sectional area of the reinforced column and equal area of non-shrinkable sand/cement grout. The depth of the pocket is governed by the bond length of the column reinforcement. This should be a full tension bond length if the column is designed at the balanced section. However it is most unlikely that this will be the case in high storey frames and so strictly speaking one should calculate the actual tensile stress in the bar and provide a subsequent bond length. To evade using very deep pockets when using large diameter bars it will be essential to provide a hook to the bottom of the bar. The minimum bond length, and hence pocket depth, should not be less than 12 times the bar diameter. The size of precast column is 300 mm X 500 mm and the total socket depth and wall thickness is 600 mm and 150 mm. The strength of infill used for grouting is M30 Grade. The sectional view of pocket foundation and reinforcement detailing in column socket is shown in figure 1.

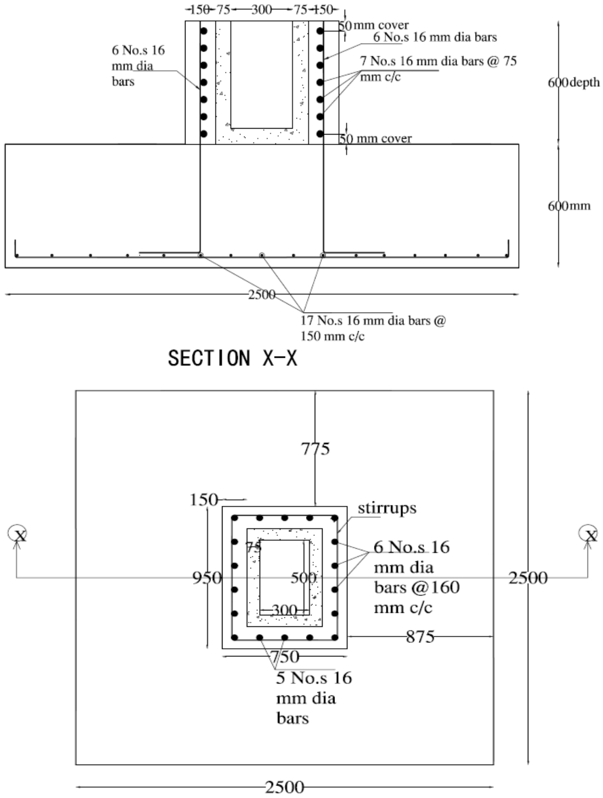

Fig. 2. Detailing of isolated footing and pocket.

C. Design and Detailing of Grouted Sleeve Connection

Grouted sleeve connections are used to fix a precast column to foundation. In grouted sleeve connection the ducts used are made with corrugated galvanized strip steel with 80mm internal diameter and 84mm external diameter and 0.6mm thickness. Here the column size is 300×500mm and foundation size is 2500×600mm is provided. Two numbers of 16mm dia bars are extended to the bottom of the foundation from the column, which provide a proper connection between column and foundation .The ducts are provided at a height of 1150mm from the top of the foundation.

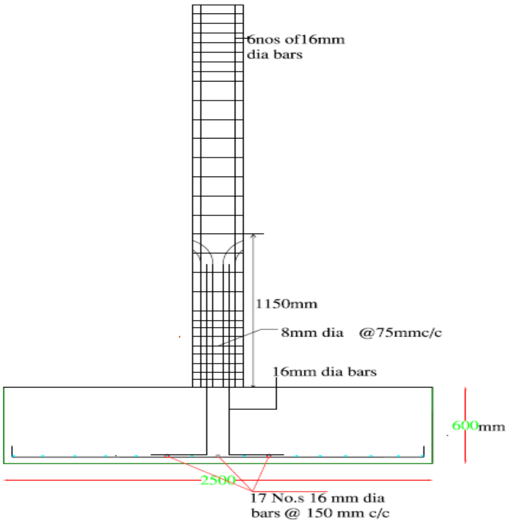

Fig. 3. Detailing of grouted sleeve connection.

D. Design and Detailing of In-Situ Socket Foundation Connection

In-situ socket foundation connection is a type of pocket foundation connection in which the socket is provided inside the foundation and the socket is then filled with grout. The depth of the socket is 1.5 times width of the column. The space between the column and socket is 100mm at the top and 50mm at the bottom. The column size is 300× 500mm and foundation size is 2500×300mm is provided.

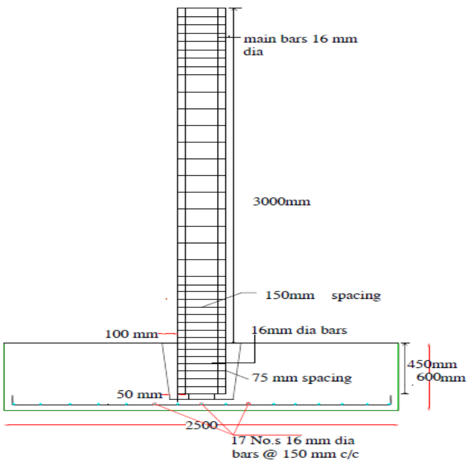

Fig. 4. Detailing of in-situ socket foundation connection.

V. MODELING BY FINITE ELEMENT SOFTWARE

A. Modeling of Pocket Foundation Connection

SOLID65 and LINK180 elements are used for modeling the pocket foundation connection.

TABLE II. Material properties of concrete.

Young's modulus	27386.12N/mm^2
Poisson's ratio	0.2
Open shear transfer coefficient	0.2
Closed shear transfer coefficient	0.8
Uniaxial cracking stress	3.83N/mm^2
Uniaxial crushing stress	30N/mm^2

Table II shows the material properties of concrete given in the software for modeling the connections.

TABLE 3. Material properties of steel.

Young's modulus	2×10^{5}N/mm^2
Poisson's ratio	0.3
Yield stress	415N/mm^2
Tangent modulus	482.75N/mm^2

In ANSYS, Solid 65 and LINK 180 element was used for the modelling of concrete, and reinforcement. The frictional contact is used to stimulate the bonding interface between pocket foundation and precast column. All the structural properties of concrete and the reinforcement were suitably given in the ANSYS software. The modelling and Meshing of Pocket foundations, Pre cast columns and the whole assembly of connections obtained from the finite element software ANSYS is shown in the figure 5.

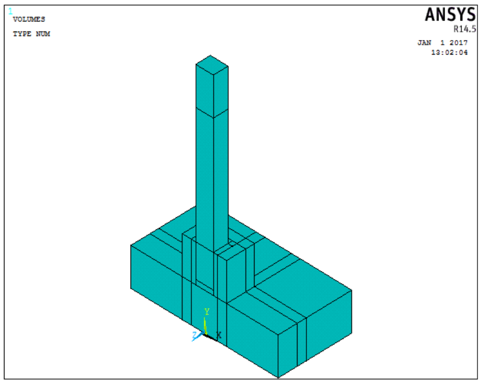

Fig. 5. Model of pocket-foundation connection.

Meshing

In FEA, an engineering configuration is divided into small elements. These elements should agree with the geometry of the structure and correspond to the geometry and the mechanical properties in the regions. It is better advisable to keep the elements size smaller enough to succumb the good results and yet largely reduces the computational time. In the place where the results are changing rapidly (change in geometry, sharp corners, etc.), the smaller elements are desirable and if the results (deflection or stresses) are relatively constant, the larger elements can be used.

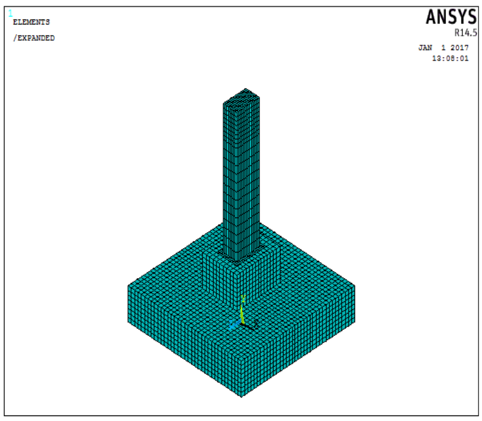

Fig. 6. Meshing of the model.

In ANSYS FEA programs have the facility of automatically generating FEA mesh. In manual meshing, we have to provide the type of element and its mechanical properties, loads and support condition. Meshing of the whole arrangements was done in ANSYS by giving the appropriate size of mesh and mesh generation of the whole assembly was shown in figure 6.

Loading and Boundary Conditions

Since the foundation was seated in the ground and surrounded with soil mass the foundation was given with the fixed support condition. After fixing the support condition to the foundation loading arrangement was given to the column. In loading there are two types of loads, one is the vertical load that acted vertically to the column and another one is the earthquake loading that is acted horizontally along the connection of column and foundation in the ground level. The loads are taken from the design data of the connection details.

B. Modelling of Grouted Sleeve Connection

Grouted sleeve connections are used to fix a precast column to foundation. In grouted sleeve connection the ducts used are made with corrugated galvanized strip steel with 80mm internal diameter and 84mm external diameter and 0.6mm thickness.Solid65 and link180 element was used for modeling concrete and reinforcement respectively.

Modelling

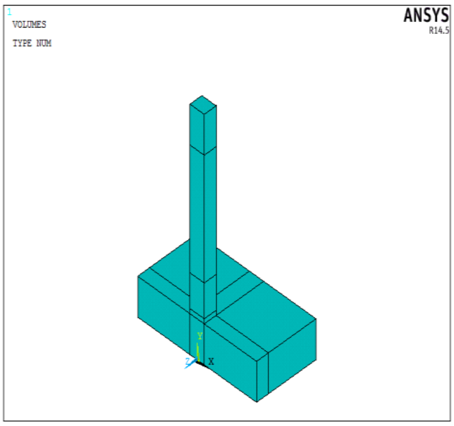

Fig. 7. Model of grouted sleeve connection.

Meshing

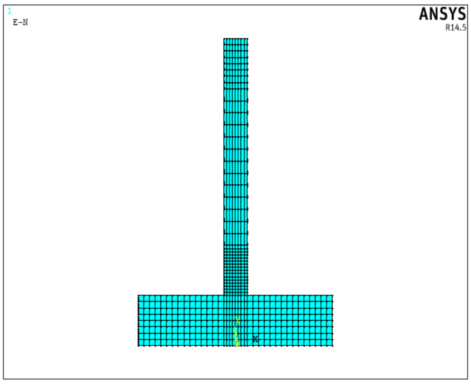

Fig. 8. Meshing of grouted sleeve connection.

Loading and Support Condition

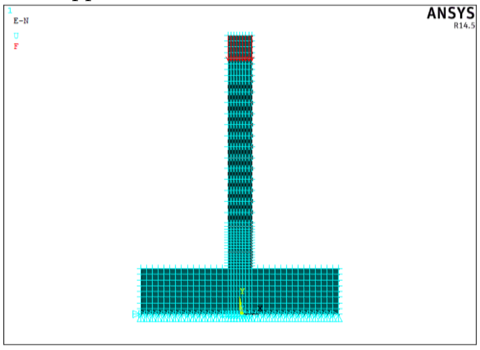

Fig. 9. Loading and boundary conditions.

C. Modelling of in Situ-Socket Foundation Connection

Modelling

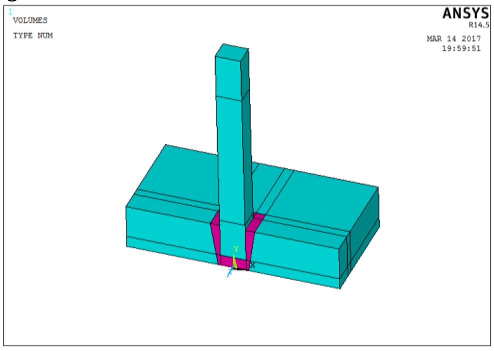

Fig. 10. Model of in-situ socket foundation connection.

Meshing

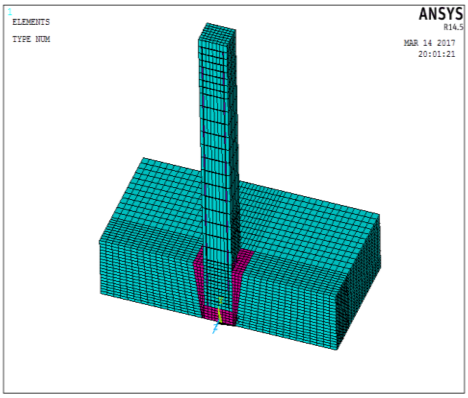

Fig. 11. Meshing of in-situ socket foundation connection.

Loading and Support Condition

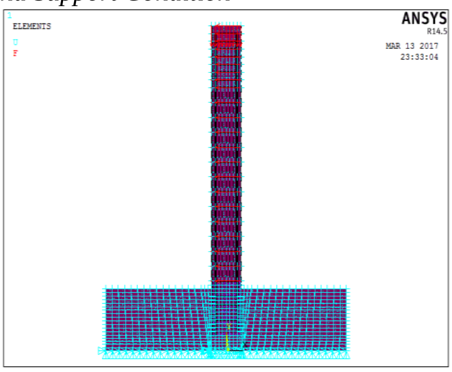

Fig. 12. Loading and boundary conditions.

VI. Results and Discussions

Static non linear analysis is used to analyse the structure.

Experimental Results

A. Displacement Diagrams

The figure 13 shows the displacement diagram of pocket foundation connection due to the critical load acting on the column. Yielding of the specimen was initially starts at the column top. It shows that the member is initially getting yield before the connection yield. The pocket depth and the thickness are sufficient to withstand the base shear and the failure of connection is avoided. The maximum value of deflection is 3.88mm and the minimum value is0.432mm.The value of deflection is within the permissible limit as per IS456:2000. There is no cracks in concrete.

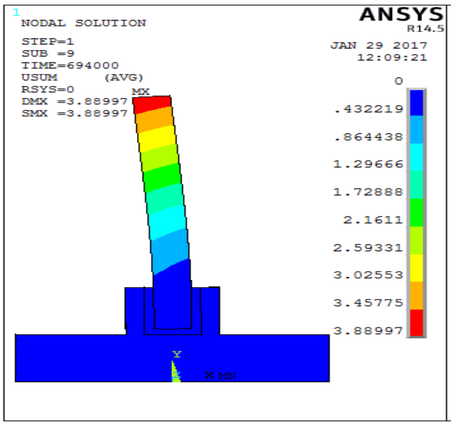

Fig. 13. Displacement diagram for pocket foundation connection.

The figure 14 shows the displacement diagram of grouted sleeve connection when the critical load (from ETABS) is acting on the column. The maximum deflection is at the top of the column. The value of maximum deflection is 3.68mm and the minimum value is 0.41mm.The value of deflection is within the permissible limit as per IS456:2000.There is no development of cracks in concrete.

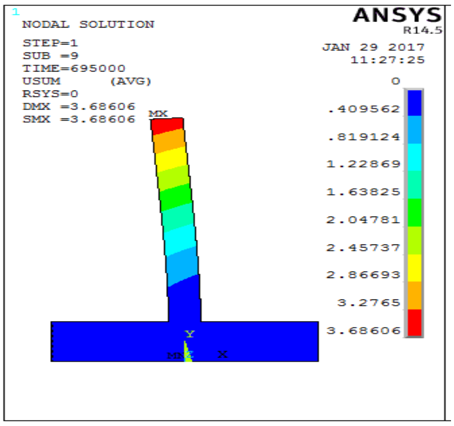

Fig. 14. Displacement diagram for grouted sleeve connection.

The figure 15 shows the displacement diagram of in-situ socket foundation connection when the critical load is acting on the column. From the figure we can see the maximum deflection is occurs at the top of the column. The maximum value of the deflection is1.91mm and the minimum value of deflection is 0.21mm. The value of deflection is within the limit as per IS456:2000.When comparing the results of three foundation connections we can conclude that among the three connections in-situ socket foundation connection has less value of deflection for the same loading condition. The value of deflection is more for pocket foundation connection

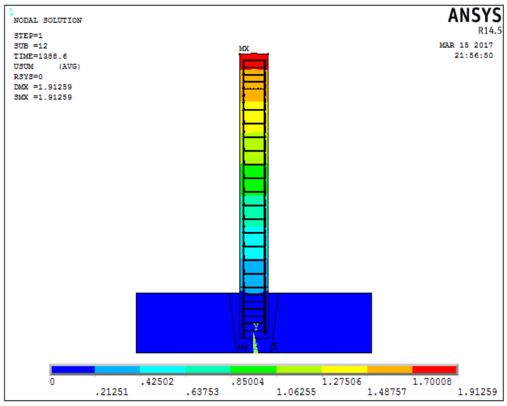

Fig. 15. Displacement diagram for in-situ socket foundation connection.

B. Principle Stress Diagrams

Figure 16 shows the principle stress diagram for pocket foundation connection. From the figure we can see that the maximum value of stress obtained is 5.39N/mm^2. The limiting value of stress is 30N/mm^2. So the value obtained is within the limit. Hence the connection is safe.

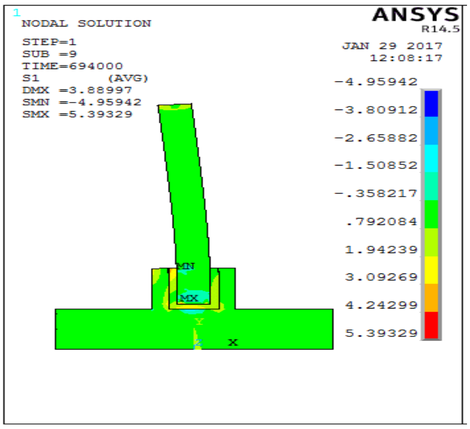

Fig. 16. Principle Stress diagram for concrete (Pocket foundation).

Figure 17 shows the principle stress diagram for grouted sleeve connection. From the figure we can see that the maximum value of stress obtained is 3.73N/mm^2. The limiting value of stress is 30N/mm^2. So the value obtained is within the limit. Hence the connection is safe.

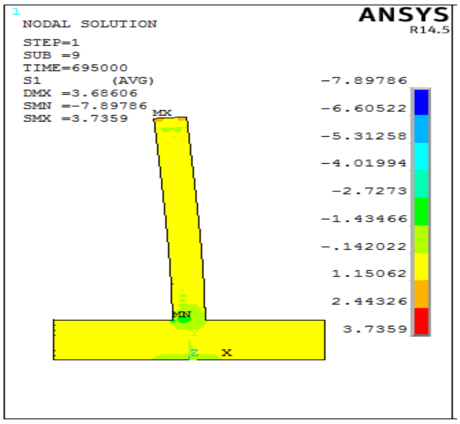

Fig. 17. Principle stress diagram for concrete (Grouted sleeve connection).

Figure 18 shows the principle stress diagram for in-situ socket foundation connection. From the figure we can see that the maximum value of stress obtained is 12.64N/mm^2 The limiting value of stress is 30N/mm^2. So the value obtained is within the limit. Hence the connection is safe.

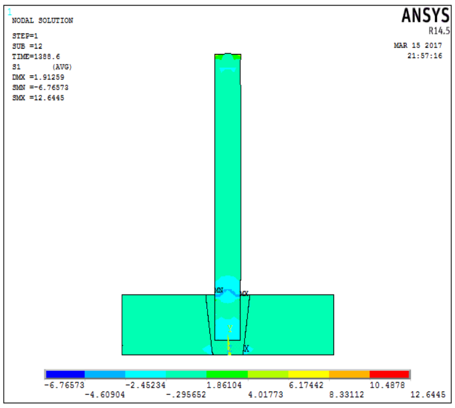

Fig. 18. Principle stress diagram for concrete (In-situ socket foundation).

When comparing the principle stress values of three foundation connections we can concluded that the value of stress in concrete is less for grouted sleeve connection and more for in-situ socket foundation connection for the same loading condition.

C. Von-Mises Stress Diagrams

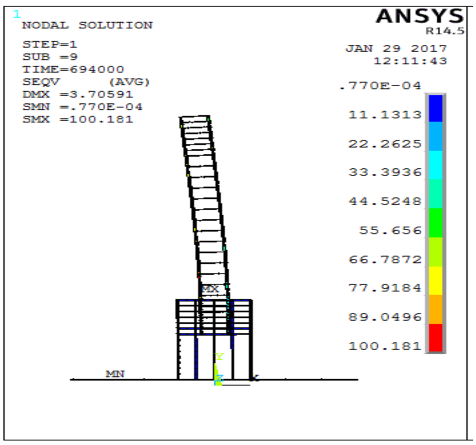

Fig. 18. Vonmises stress for reinforcement (Pocket foundation).

Figure 18 shows the results of von-mises stress developed in the reinforcement in pocket foundation connection. The value of stress obtained is 100.18N/mm^2. The limiting value of von-mises stress is 415N/mm^2. So the obtained value is within the limit. So the connection is safe.

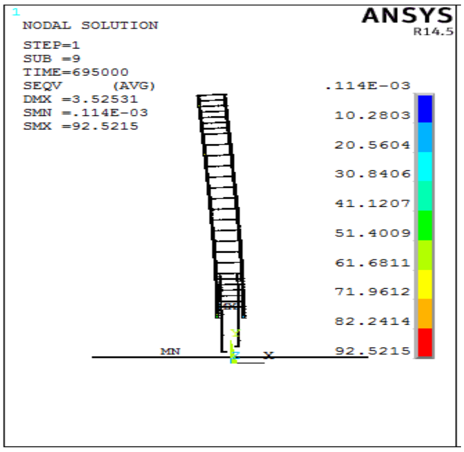

Fig. 19. Von-misess stress in reinforcement (Grouted sleeve connection).

Figure 19 shows the results of von-mises stress developed in the reinforcement in grouted sleeve connection. The value of stress obtained is 92.52N/mm^2. The limiting value of von-mises stress is 415N/mm^2. So the obtained value is within the limit. So the connection is safe.

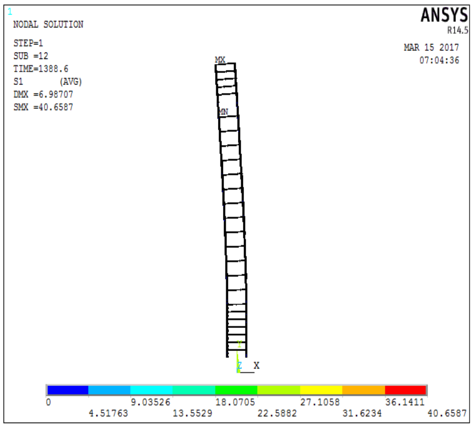

Fig. 20. Vonmisess stress in reinforcement (In-situ socket foundation).

Figure 20 shows the results of von-mises stress developed in the reinforcement in in-situ socket foundation connection. The value of stress obtained is 40.65N/mm^2. The limiting value of von-mises stress is 415N/mm^2. So the obtained value is within the limit. So the connection is safe.

From these results we can concluded that the three connections are safe. When comparing the values of vonmises stress, in-situ socket foundation connection has the least value among the three foundation connections. So the stress in steel is less for in-situ socket connection. The value of stress is more for pocket foundation connection.

D. Tabulation of Results

The results obtained from the analysis is tabulated in table IV.

TABLE IV. Comparison of results.

	Pocket foundation connection	**Grouted sleeve connection**	**In-situ socket foundation connection**
Maximum value of deflection(mm)	3.88mm	3.68mm	1.91mm
Maximum value of principle stresses(N/mm^2)	5.39N/mm^2	3.7N/mm^2	12.64 N/mm^2
Maximum value of vonmises stresses(N/mm^2)	100.18N/mm^2	92.53N/mm^2	40.65 N/mm^2
Base shear (kN)	15.81kN	16.80kN	20.12kN

From the table 4 we can see that the value of deflection is less for in-situ socket foundation connection among the three foundation connections. There is 50.77% reduction in deflection when compared with other two connections.

When comparing the principle stress values grouted sleeve connections have the least value of stress. The value of stress is 57.35% less than pocket foundation and 70.4% less than in-situ socket foundation connection.

When comparing the vonmises stresses, in-situ socket foundation connection has lesser value among the three connections. There is about 59.4% reduction in von-mises stress for in-situ socket foundation when compared with other two connections.

The base shear value is more for in-situ socket foundation connection than other two connections.

VII. Conclusion

From the analytical study of Pocket foundation connection, grouted sleeve connection and in-situ socket foundation connection by using ANSYS software the following conclusions are obtained;

- Among the three foundation connections in-situ socket foundation connection has the least value of deflection
- There is 50.77% reduction in deflection for in-situ socket foundation when compared with other foundation connections
- The value of principle stress is more for in-situ socket foundation connection among the three foundation connections
- The principle stress value of in-situ socket foundation connection is 70.4% more than the grouted sleeve connection and 57.35% more than pocket foundation connection
- This increment in stress may due to the filling of grout in the socket
- The value of von-mises stress is less for in-situ socket foundation connection among the three connections.
- There is about 59.4% reduction in von-mises stress for in-situ socket connection when compared with other two foundation connections.
- From observations we can concluded that the in-situ socket foundation connection is a better connection in high seismic regions
- It gives a better seismic resistance and seismic stability of the structure among the three foundation connections
- So we can choose in-situ socket foundation connections in high seismic regions.

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