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Repairing of Heavily Cracked Unbonded Post-Tensioned Structural Systems

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ABSTRACT- Reinforced concrete moment resisting frames (RCMRF) are structural systems that should be designed to ensure proper energy dissipation capacity when subjected to seismic loading. In this design philosophy the capacity design approach that is currently used in practice demands “strong-column / weak-beam” design to have good ductility and a preferable collapse mechanism in the structure. When only the flexural strength of longitudinal beams controls the overall response of a structure, RC beam-column connections display ductile behavior (with the joint panel region essentially remaining elastic). The failure mode where in the beams form hinges is usually considered to be the most favorable mode for ensuring good global energy-dissipation without much degradation of capacity at the connections. Though many international codes recommend the moment capacity ratio at beam column joint to be more than one, still there are lots of discrepancies among these codes and Indian standard is silent on this aspect.

KEYWORDS- Linear & Non-Linear analysis, RCC & Precast beam-column connections, Seismic, Prestressed Ground Motion, Panel building

I. INTRODUCTION

Precast concrete systems have many advantages like speed in construction, good quality due to factory production, economy in mass production. Despite these advantages of precast concrete, it is not widely used throughout the world, especially in regions of high seismic risk.

The reason behind this is lack of confidence and knowledge base about their performance in seismic regions as well as the absence of rational seismic design provisions in major model building codes (Priestley, 1991). High storey precast frame panel buildings performed poorly in the 1988 Spitak, Armenia earthquake due the lack of adequate seismic design considerations such as ductility in precast joints (Hadjian, 1993). A significant number of parking structures suffered extensive damage and a number of precast concrete parking structures collapsed in the 1994, Northridge earthquake. One of the reasons for the collapse was lack of proper diaphragm connections (Mitchell et al., 1995).

In the 1995 Kobe earthquake, most of the precast prestressed concrete structures performed well, only three sustained severe structural damage. The structural damage was due to insufficient connection detailing (Muguruma et al., 1995). The lessons learnt from the past earthquakes are that the connections are the weakest link. Hence more research is required in the study of connections.

For Purpose of Rehabilitation and protection against seismic actions concerns a large number of buildings made of precast and prestressed concrete elements, basically for industrial-manufacturing purposes. These buildings are very common in many countries and especially in Italy, where a large number of constructions were built in the ‘50s, ‘60s and ‘70s, during the reconstruction after World War II and the consequent economic and social development. At that time the buildings were characterized by innovative and even high - performance materials and by complex structural solutions exploiting new material and design approaches. The latter however were not comparable with modern regulations and technical knowledge, so that assessment of present conditions needs specific studies on local and global behavior. This circumstance is more relevant if seismic risk is analyzed; in fact, many constructions are located in areas recognized to be exposed to seismic risk after erection, so that the original design takes into account only gravity loads, without any consideration of lateral loads due to earthquake

A. Beam-Column Connections

The beam-column connection is one of the few vital regions determining the seismic resistance efficiency of a framed or partially-framed structure. The present need is to develop a rational analytical model capable of predicting the ultimate capacity of a variety of embedded steel member precast connections. The development of this analytical model is based on the results of a series of experiments in which the different variables like effect of column axial load, effect of additional welded reinforcement, effect of shape of embedded member were studied. The analytical model has been used to construct a series of non-dimensional design curves for connections with or without additional welded reinforcement. The connection between the beam and column must be strong enough as it serves as part of the vertical load resisting system in order to comply with one of the failure modes in which the beams must fail before columns. Under earthquake loading, the joint will be the most critical area to resist the lateral seismic reaction forces. Its characteristics affect the global behavior of the whole structure, particularly when subjected to seismic loading.

Therefore, the strength of the joint has to be higher than the strength of the member it joins. This makes the proper reinforcement of this zone difficult to construct and not fully established. The designed joint failed in shear and the beam bars slipped only after the first cycle of inelastic loading. Precast concrete has been recognized as a feasible means of building structural structures that are secure, robust, efficient, quality, and cost-effective. However, its application in high seismic regions has been restricted, mostly because of the lack of availability of construction standards relative to those required for concrete frameworks cast in place. Over the years, the introduction of precast concrete has demonstrated benefits of concrete production, such as better quality protection, smoother construction schedule management, effective usage of resources and cost savings.

II. METHODOLOGY

A. Methodology Steps

1) Collection of Data

- Study of Time History

2) Study of Connections

- RCC Beam Column Connection
- Precast Beam Column Connection

3) Software Modeling

- Building modeling and analysis in STAAD Pro.
- Modeling of Beam column connection in ANSYS.
- Result and Conclusion.

B. Ground Motions and Linear Time History Analysis

Dynamic analysis using the time history analysis calculates the building responses at discrete time steps using discredited record of synthetic time history as base motion. If three or more time history analyses are performed, only the maximum responses of the parameter of interest are selected.

In order to study the seismic behavior of structures subjected to low, intermediate, and high-frequency content ground motions, dynamic analysis is required. The STAAD Pro software is used to perform linear time history analysis.

Two, six, and twenty-story regular as well as irregular RC buildings are modeled as three-dimension. Material properties, beam and column sections, gravity loads, and the six ground motions listed in Table 4.3 are assigned to the corresponding RC buildings and then linear time history analysis is performed. The linear time-history analysis results for regular and irregular RC buildings are shown in chapter 5 and 6 respectively.

1) Ground Motion Records

Buildings are subjected to ground motions. The ground motion has dynamic characteristics, which are peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), frequency content, and duration. These dynamic characteristics play predominant role in studying the behavior of RC buildings under seismic loads. The structure stability depends on the structure slenderness, as well as the ground motion amplitude, frequency and duration. Based on the frequency content, which is the ratio of PGA/PGV the ground motion records are classified into three categories:

High-frequency content PGA/PGV > 1.2
Intermediate-frequency content 0.8< PGA/PGV< 1.2
Low-frequency content PGA/PGV < 0.8

It is difficult to determine accurately the ground velocity and displacement because analog accelerographs do not record the initial part until the accelerograph is triggered of the acceleration-time function and thus the base line is not known. Digital accelerographs overcome this problem by providing a short memory so that the onset of ground motion is measured. There are several different versions of the ground motion. The variations among them arise from differences in how the original analog trace of acceleration versus time was digitized into numerical data, and the procedure chosen to introduce the missing baseline in the record.

2) Material Modeling

The definition of the proposed numerical model was made by using finite elements available in the ANSYS code default library. SOLID186 is a higher order 3-D 20- node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials. The geometrical representation of is show in SOLID186 fig 3.9.

This SOLID186 3-D 20-node homogenous/layered structural solid were adopted to discrete the concrete slab, which are also able to simulate cracking behavior of the concrete under tension (in three orthogonal directions) and crushing in compression, to evaluate the material non-linearity and also to enable the inclusion of reinforcement (reinforcement bars scattered in the concrete region).The element SHELL43 is defined by four nodes having six degrees of freedom at each node. The deformation shapes are linear in both in-plane directions. The element allows for plasticity, creep, stress stiffening, large deflections, and large strain capabilities.

The representation of the steel section was made by the SHELL 43 elements, which allow for the consideration of non-linearity of the material and show linear deformation on the plane in which it is present. The modeling of the shear connectors was done by the BEAM 189 elements, which allow for the configuration of the cross section, enable consideration of the non-linearity of the material and include bending stresses as shown in fig 3.5. CONTA174 is used to represent contact and sliding between 3-D "target" surfaces (TARGE170) and a deformable surface, defined by this element.

The element is applicable to 3-D structural and coupled field contact analyses. The geometrical representation of CONTA174 is show in fig 3.5.

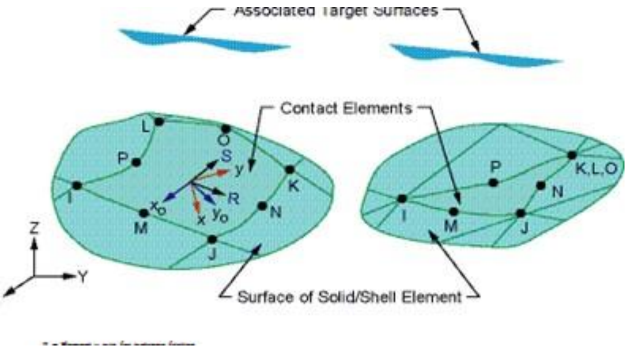

Figure 1: CONTA 174

Contact pairs couple general ax symmetric elements with standard 3-D elements. A node-to-surface contact element represents contact between two surfaces by specifying one surface as a group of nodes. The geometrical representation of is show in TARGET 170 fig 3.

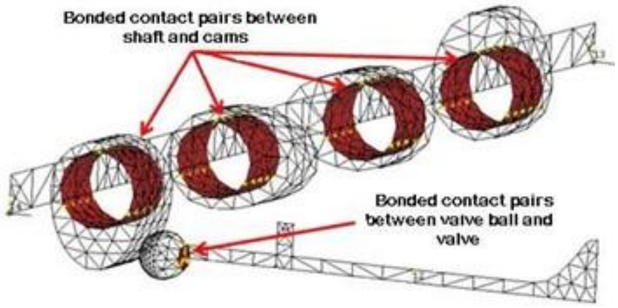

Figure 2: TARGET 170

The TARGET 170 and C0NTA 174 elements were used to represent the contact slab- beam interface. These elements are able to simulate the existence of pressure between them when there is contact, and separation between them when there is not. The two material contacts also take into account friction and cohesion between the parties.

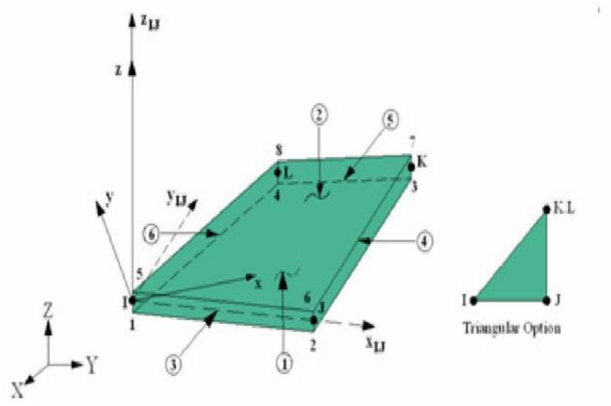

Figure 3: Shell

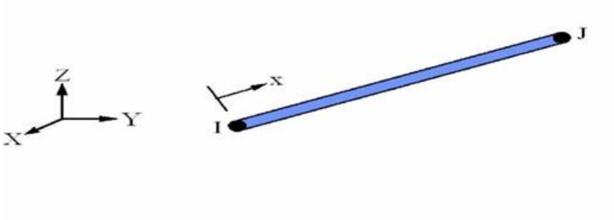

Figure 4: Beam

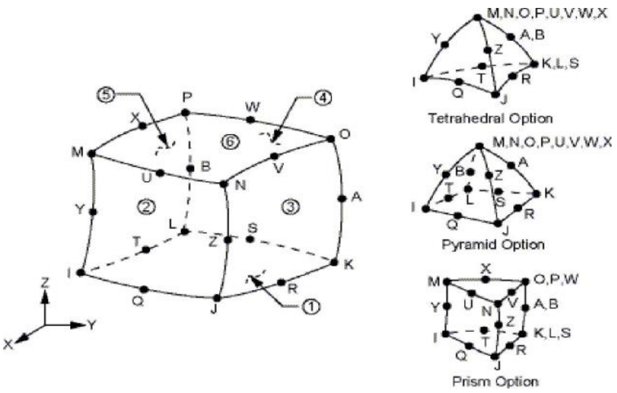

Figure 5: Solid 186

3) *Material properties*

Table 1: Material Property of steel and concrete

Sr. No.	Material	Property	Value
1	Structural steel	Yield stress *fsy* (MPa)	265
		Ultimate strength *fsu* (MPa)	500
		Young’s modulus *Es* (MPa)	205×10^3
		Poisson’s ratio µ	0.3
		Ultimate tensile strain et	0.25
3	Concrete	Compressive strength *fsc* (MPa)	25
		Tensile strength *fsy* (MPa)	3.5
		Young’s modulus E*c* (MPa)	32920
		Poisson’s ratio µ	0.15
		Grade of concrete	M25

4) Analysis of model

The analysis results of the G+9 RCC Commercial Building in STAAD.Pro is shown in the figure 4.3.1. The highlighted lines in the model shows the columns and beams with highest beam end forces.

C. Details for ANSYS Models for Precast and RCC

Column Size – 300 x 750 mm Reinforcement for Column – 12T – 16No Beam Size – 230 x 450 mm Reinforcement for Beam – Top – 12T -2, Bottom- 12T -2, Shear – 10T@120 C/C Total Maximum Load – 1824 KN

D. Details of Precast Models

Table 2: Precast Models

Sr.No.	Model No.	Description
1	RCC	Monolithic beam column joint
2	Precast Model 1	Precast beam column with trapezoidal haunch size 0.3 x 0.45 with 2 bolts of 20mm diameter Gusset plate of 30mm thickness
3	Precast Model 2	Precast beam column with rectangular haunch size 0.2 x 0.45 2 bolts of 20mm diameter Gusset plate of 30mm thickness
4	Precast Model 3	Precast beam column with haunch size 0.2 x 0.252 bolts of 20mm diameter Gusset plate of 30mm thickness

III. RESULT AND DISCUSSION

The results obtained from the analysis of models in ANSYS are shown in tables and graphs. From Graph 5.2 it clearly shows that the total deformation in conventional RCC beam column junction is more than precast beam column junction. The normal stress, shear stresses and maximum principal stresses in precast model no. 1, 2 and 3 is more as compared to RCC beam column junction as seen in the Graphs 5.2, 5.3 and 5.4. In precast the stresses are concentrated in the connecting elements.

A. Maximum Deformation M25

Table 3: Maximum Deformation of M25

LOAD (N) vs DEFORMATION (mm)				
LOAD (N)	**RCC MODEL**	**PRECAST MODEL NO.1**	**PRECAST MODEL NO.2**	**PRECAST MODEL NO.3**
100	0.32612	3.53E-02	3.84E-02	4.01E-02
200	0.46801	7.06E-02	7.68E-02	8.02E-02
300	0.61655	0.10594	0.11521	0.12036
400	0.82207	0.14125	0.15361	0.16047
500	1.0276	0.17656	0.19202	0.20059
600	1.2331	0.21187	0.23042	0.24071
700	1.4386	0.24712	0.26883	0.28083
800	1.6441	0.2825	0.30723	0.32095

Above table shows the result for Maximum Deformation for all models, the results conclude that the Deformation for precast model no 1 is less than the other precast patterns and RCC model, by around 5-10% for precast models and 30-40% for RCC model

B. Normal Stress M25

Table 4: Normal Stress of M25

LOAD (N) vs NORMAL STRESS (MPa)				
LOAD (N)	**RCC MODEL**	**PRECAST MODEL NO.1**	**PRECAST MODEL NO.2**	**PRECAST MODEL NO.3**
100	0.055322	6.53E-01	3.57E-01	4.01E-02
200	0.11064	1.31E+00	7.13E-01	8.02E-02
300	0.16597	1.9597	1.0689	0.12036
400	0.22129	2.6129	1.431	0.16047
500	0.27661	3.2662	1.7889	0.20059
600	0.33193	3.9194	2.1467	0.24071
700	0.38725	4.5715	2.5045	0.28083
800	0.44258	5.2259	2.8623	0.32095

Above table shows the result for Normal Stress for all models, the results conclude that the Normal Stress for precast model no 3 is less than the other precast patterns and RCC model, by around 15-20% for precast models and 40-50% for RCC model

IV. CONCLUSION AND SCOPE OF STUDY

In this project the comparative analysis is made for RCC and PRECAST beam column connections and following conclusions are as observed:

- The result for Maximum Deformation for all models, the results conclude that the Deformation for precast model no 1 is less than the other precast patterns and RCC model, by around 5-10% for precast models and 30-40% for RCC model
- The result for Normal Stress for all models, the results conclude that the Normal Stress for precast model no 3 is less than the other precast patterns and RCC model, by around 15-20% for precast models and 40-50% for RCC model
- The result for Shear Stress for all models, the results conclude that the capacity of Shear Stress for RCC model is less than the other precast patterns, by around 30-35%
- The result for Maximum Principal Stress capacity for all models, the results conclude that the capacity of Maximum Principal Stress for RCC model is less than the other precast patterns, by around 40-45%
- The maximum deformation is reduced by 15-20 % in to Precast beam column connections as compared to RCC beam column connections.
- From the analytical study of the different shapes of beam column connection it is found that the precast connection is more effective as compared to RCC.
- The Normal Stresses, Shear Stresses, Equivalent stresses, Principal stresses are observed more at connecting elements of precast.
- The time history analysis result for Total Deformation mm for all models, the results conclude that the Total Deformation mm for RCC model is greater than the other precast patterns, by around 10-20%, and less for model no 3
- Above graph shows the time history analysis result for Shear Stress for all models, the results conclude that the Shear Stress for RCC model is greater than the other precast patterns, by around 25-30%, and less for model no 3
- The time history analysis result for Max. Principal Stress for all models, the results conclude that the Max. Principal Stress for RCC model is greater than the other precast patterns, by around 20-25%, and less for models no 3
- The time history analysis result for Normal Stress for all models, the results conclude that the Normal Stress for RCC model is greater than the other precast patterns, by around 10-15%, and less for models no 3
- The time history analysis result for Equivalent Stress for all models, the results conclude that the Equivalent Stress for RCC model is greater than the other precast patterns, by around 10-15%, and less for models no 3

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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