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Seismic Performance Assessment of Pre-Stressed Precast RC Structure Using Non-Linear Static Procedure

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***Abstract:*— The prefabricated pre-stressed reinforced concrete structures are becoming popular in various parts of the globe due to its good quality control and less erection time as compared to cast in-situ RC structure. However, in Indian construction industry use of such building systems is not gaining impetus due to hesitation of structural designers concerning its seismic safety. Although, some past analytical and experimental study conducted elsewhere indicates that the pre-stressed precast reinforced concrete (PPRC) structures can perform well under seismic loading. The improvement in seismic performance was observed due to the use of pre-stress post tensioned tendons connecting beam-column interface. In case of PPRC structure, the joints are not monolithic and hence the overall force distribution in the beam-column framing system will be different than that of monolithic reinforced concrete (MRC) frame structure. Therefore, the present work proposes a new iterative process of linear analysis to determine the internal elemental forces viz. bending moment, shear force and axial load for PPRC structure. Pre-stressed precast beams and non-pre-stressed cast-in-situ columns have been considered for 3D modelling of the building. The nonlinear moment-rotation properties for beam-column interface are obtained from monolithic beam analogy. The comparative study of linear analysis results and non-linear seismic performance of MRC structure as well as PPRC structure has been performed.**

***Index Terms* :-- Non-Linear Static Procedure, Pre-Stressed Precast RC Structure (PPRC), Seismic Performance Assessment.**

I. INTRODUCTION

Precast elements means reinforced concrete structural element is cast and cure under controlled environment in manufacturing plant. Developed mature concrete element is transported to construction site and assembled to form a structure. Use of precast construction reduces the construction time as compare to MRC structures. In addition to this precast construction allows designers to perform more innovative designs. The ambiguous performance of precast buildings in the past earthquake has been reported in literature. Report on performance of precast buildings during Northridge earthquake by Iverson and Hawkins [1] and Chile earthquake by Ghosh and Cleland [2] stated that by and large these buildings performed well with minor structural damage. Contrary to this, during Kocaeli and Duzce earthquake, Ozturk and Ozturk [3] observed that the damage to precast structure was mainly due to improper beam-column connection. Further, during Emilia earthquake, Magliulo et al. [4] observed that failure in precast structure is due to use of pin beam-column connection. During Turkey earthquake, Ozden et al. [5] observed that most of the precast buildings were severely damaged at joints and results in global failure of structure. However, few well designed precast building performed exceptionally well. The common observation found in the literature that prefabricated constructions generally fails at connection and consequently results in the failure of building. This implies that performance of assembled precast frame structure is greatly influenced by performance of beam-column connection. To overcome this beam-column connection problem, four types of dry connection was proposed after extensive research under PRESSS (PREcast Seismic Structural System) test programme viz. Hybrid, Pre-tensioned, TCY (tension compression yielding) and TCY-Gap [6]. In hybrid connections the un-bonded post-tensioned tendons and partially grouted mild steel is used. The post-tensioned un-bonded tendons are used to transfer shear and to maintain integrity of complete frame. The mild steel bars are provided to increase the ductility of connections. The schematic diagram of hybrid connection is shown in Fig. 1 taken from reference [6]. The fixity between beam and column at the interface depends on amount of pre-stress. Moreover, the rotational behavior of interface also depends on the level of pre-stress. The considered archetype precast building comprises of hybrid connection with precast beams connected to cast-in-place columns using post-tensioned tendon. As per IS 15916:2010 [7] precast structure should be analyzed as a

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monolithic one and the joints in them should be designed to resist forces of an equivalent discrete system. As precast connection is a semi-rigid connection and hence the code based procedure may falls out in under designed structure. Therefore a new iterative process to determine the internal elemental forces viz. bending moment, shear force and axial load for PPRC structure is proposed in this study. Details of procedure is discussed under heading 'analysis and design' in section III.

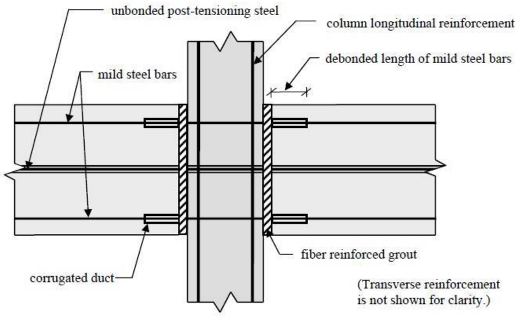

Fig.1: Detail of hybrid connection [6]

Elements are designed for the obtained design forces by the PRESSS guidelines given by Stanton and Nakaki [8] and ACI T1.2-03 [9]. The moment rotation and initial stiffness is calculated by monolithic beam analogy (MBA) proposed by Pampanin et al. [6].

II. SELECTION OF PLAN

The same plan of five storey building used in PRESSS test programme is selected for the present study (shown in Fig.2). The details of beam, column and shear wall is given in Table I. Equivalent static analysis of structure has been performed as per IS 1893 part 1 (2002) [10] for both monolithic and precast models, for different earthquake zones (i.e. zone II, zone III, zone IV and zone V).

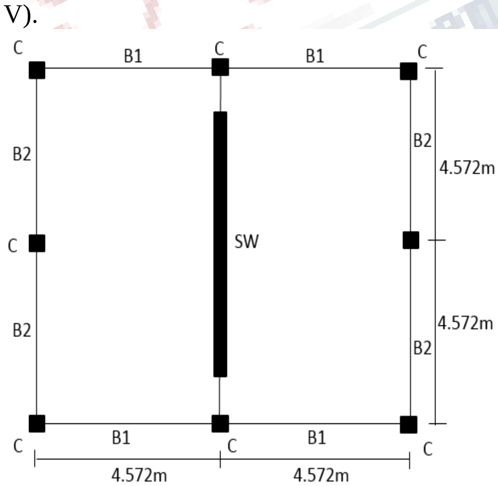

Fig.2: Plan of building

Table I: Sizes of elements

Elements	Sizes (mm x mm)
Beam (B1)	360 x 610
Beam (B2)	220 x 410
Column (C)	460 x 460
Shear Wall (SW)	205 x 5500
Slab	150 mm

III. ANALYSIS AND DESIGN

In MRC frame, the beam-column connections are rigid, and therefore, they are capable of resisting rotations, displacements and distortions. Whereas, in hybrid pre-stressed precast frame, the rigidity in beam-columns connection depends on the pre-stressing force. Comparatively, the frames with hybrid connections are relatively flexible than MRC frames. In hybrid beam-column connections the bending moments are transferred through flexural actions similar to a traditional MRC frame, whereas, the shear forces is transferred through the frictional resistance induced by post tensioning tendons. Results of monolithic beam analogy and various experimental observation shows that precast connections are semi-rigid type connection. Since the behavior of PPRC frame differs from MRC frame, the use of internal forces obtained from MRC frame analysis for design of PPRC will result in faulty design. Therefore, in order to obtain realistic design forces, it is necessary to assign appropriate hybrid connection stiffness in analytical modeling. The diagrammatic representation of general analysis and design process used for precast system is shown in Fig.3.

To counter the internal forces in precast frames with semi-rigid connection, the present work proposes an iterative process of estimating internal forces in reference with modified joint stiffness of PPRC frame. In primary stage of analysis, connections are assumed to behave like monolithic and design forces are obtained. Further the beam-column interface of the frame is designed by PRESSS guidelines [8] and ACI T1.2-03 [9]. As monolithic beam analogy (MBA) gives fair estimation of moment rotation behavior of beam-column interface, the rotational stiffness of newly designed interface is estimated using MBA. The assumption of monolithic interface is not valid and to catch the realistic behavior of PPRC structure the mathematical model of PPRC frame is modified with estimated linear rotational stiffness. The process of analysis and design is repeated which will results in new rotational stiffness. The same iterations are performed until compatibility of internal forces and respective rotational stiffness of designed beam-column interface is achieved. Diagrammatic representation of aforementioned iterative analysis process is shown in Fig.4. Structural modelling, analysis and design have been performed in SAP

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2000 version 14.2.4. Detailed mathematical model has been prepared to represent the distribution of structural geometry of elements and loading in plan as well as in elevation. Thickness of slab at all floor level and roof level have been assumed to be same and modelled as rigid diaphragm. Archetype building has been analyzed by using equivalent static analysis and designed as special moment resisting frame as per the specifications of Indian Standard Codes [7], [10]-[13].

Initially for monolithic case, the beams have been assigned with default moment (M3) hinges and columns with coupled axial moment (P-M2-M3) hinges at the two ends as per FEMA 356 [14]. For precast case, Rotational spring (□ 3) is attached at the beam ends with initial stiffness as per MBA.

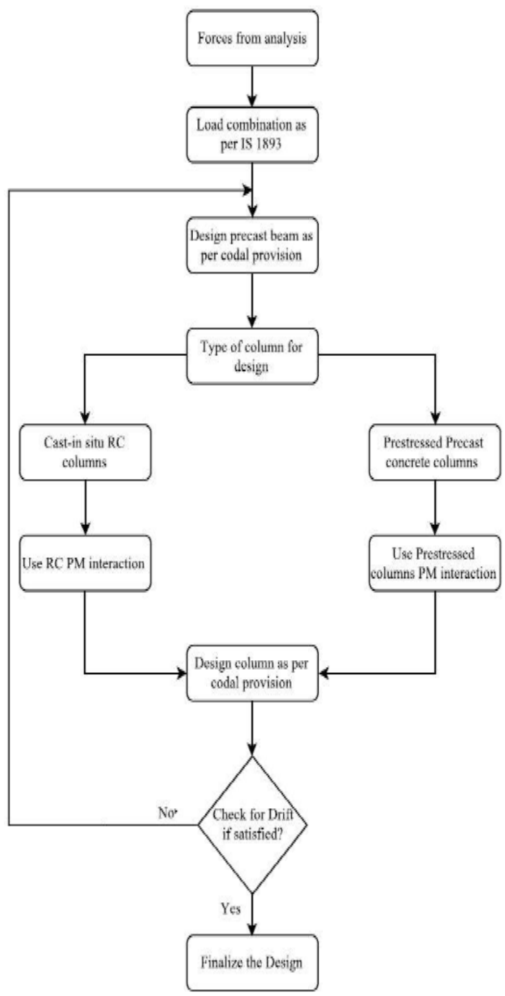

Fig.3: General analysis and design process for precast system.

To access the performance of both monolithic and precast building nonlinear static procedure i.e. static pushover analysis have been performed. Nonlinear lumped plasticity models for precast pre-stressed beam-column interface are generated using MBA and assigned at the end of beams. Default moment (M3) hinges are assigned at a relative distance of 0.1 and 0.9 in respective beam and coupled bi-axial moment (P-M2-M3) hinges are assigned at the two ends of columns. Finally non-linear static analysis procedure is performed for all the considered models.

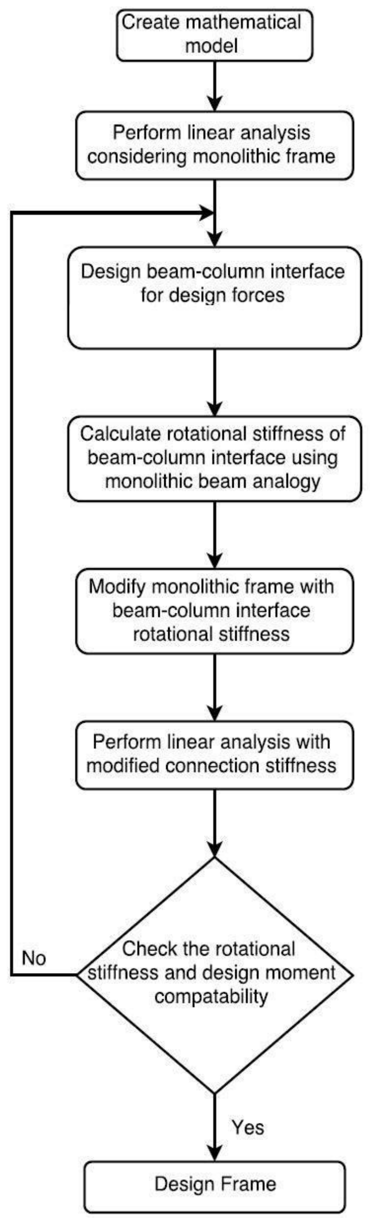

Fig.4: PPRC frame analysis process

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IV. RESULTS AND DISCUSSIONS

The results obtained from linear and nonlinear analysis of PPRC and MRC building situated in seismic zone V has been given in the graphical and tabular form. The modal analysis results are tabulated in Table II. The first mode proportionate lateral load pattern has been used to perform pushover analysis of MRC and PPRC model. The building with same structural configuration has been designed in various seismic zones. As PGA values decreases in low intensity zones, the design forces in structure is reduces. For this lesser level of design forces with same section sizes, required pre-stress is also gets reduced along with required percentage of reinforcement. Beam-column interface fixity reduces with reduction in level of pre-stress and results in relatively more flexible connection in low seismicity regions. This flexible connection falls out in relatively flexible structure with longer period of vibration and same is reflected from 1st mode elastic time period tabulated in Table II.

Table II: Modal analysis results

Models	Vibration mode 1		
	Displacement direction	Time period (s)	Modal mass participation ratio (%)
M-Z-5	T_x	0.47	82
P-Z-5	T_x	1.001	73
M-Z-4	T_x	0.47	82
P-Z-4	T_x	1.09	72
M-Z-3	T_x	0.47	82
P-Z-3	T_x	1.09	72
M-Z-2	T_x	0.47	82
P-Z-2	T_x	1.39	70

To study the internal force distribution of PPRC and MRC structure, internal forces are calculated using ESA for seismic zone V and the comparative plots of representative beam and column are shown in Fig 5-9. The columns in monolithic building following frame action as expected, however for the same zone, precast building follows cantilever action upto 3rd storey due to relative flexible behavior of pre-stressed beam-column interface. As precast structure are less stiff than monolithic frame therefore, column in precast structure will invite less shear force and axial force. Similar pattern of internal forces reduction has been observed in beam. This additional moment demand observed in PPRC frame columns shows that PPRC structure designed by considering monolithic connections are under designed one.

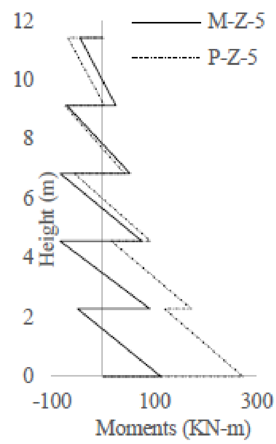

Fig.5: Column moments for zone V

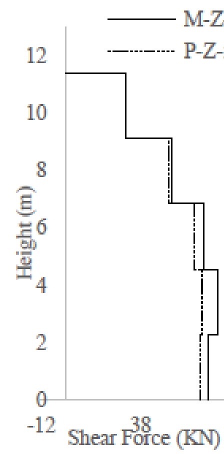

Fig.6: Column shear force for zone V

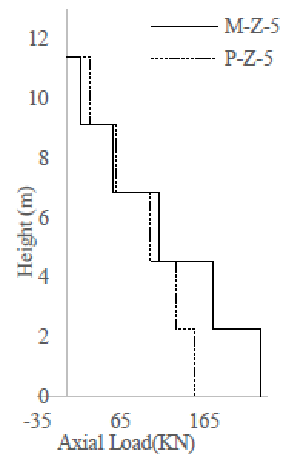

Fig.7: Column axial force for zone V

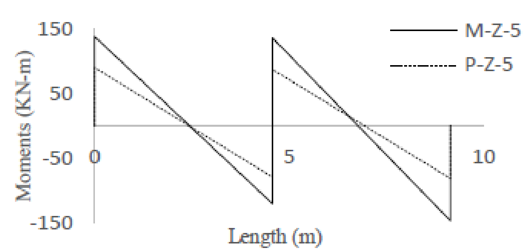

Fig.8: Beam moments for zone V

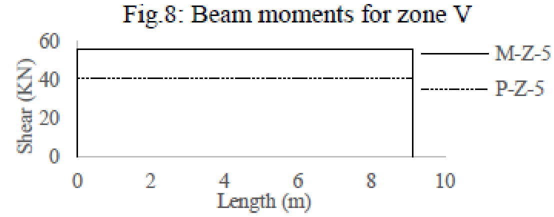

Fig.9: Beam shear force for zone V

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The comparative plot of capacity curve results of PPRC frame and MRC frame designed for seismic zone along X- direction is shown in Fig.10. In PPRC model initial stiffness of structure calculated from capacity curve is approximately 4.5 time lesser than MRC frame. The PPRC frame in high seismicity region shows better ductility performance.

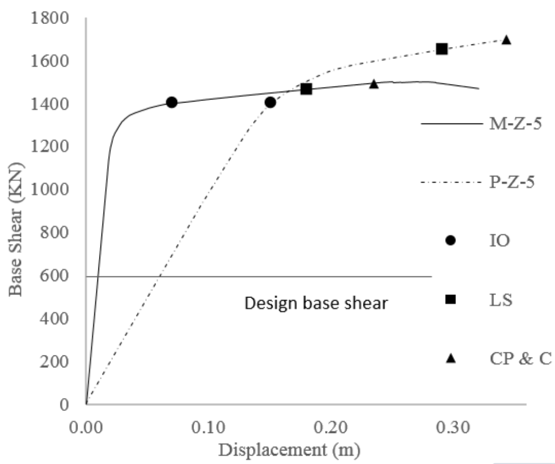

Fig.10: Capacity curve for zone V

Along with this yield base shear of PPRC structure is 9.4% more than MRC structure. Except the initial stiffness of structure overall behavior of PPRC structure is comparable to MRC frame.

V. CONCLUSIONS

The behavior of PPRC building is greatly influenced by the explicit behavior of beam column interface. The local flexible behavior of connection make structure globally flexible and can be evidenced from modal analysis results. The time period of PPRC structure increase from 1 sec to 1.39 sec (increased by 39%) in very low seismic zone (i.e. with very flexible beam column interface). These semi rigid connections alters the internal force distribution viz. frame action of column change to cantilever action and may predicts low design forces. This may give under design PPRC frame which will results in sever structural damage during seismic event. Therefore present work propose an iterative method to determine the design force compatible to semi rigid connection of PPRC frame.

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