SEISMIC PERFORMANCE OF STRUCTURAL CONCRETE BEAM-COLUMN JOINTS DESIGNED IN ACCORDANCE WITH THE PRINCIPLES OF DAMAGE AVOIDANCE

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ABSTRACT

Recent research on jointed unbounded post-tensioned precast concrete frames has demonstrated their superior seismic resistance. Inelastic rotation generated during large earthquake motions is accommodated through gap opening and closing at the beam-to-column connections in the frame. By applying the principles of Damage Avoidance Design(DAD),a steel-steel arm our ed connection has been demonstrated to be effective in protecting the precast elements from damage. The re-centring ability of the un bonded prestressed post-tensioned system allows the building to return to its original un deformed position after the earth quake with negligible residual deformations.

A theoretical model is developed based primarily on rigid body kinematics and is validated using the test results. A formulation is also developed based on St Vennants' principle, to estimate the effective stiffness of the precast concrete beams under bidirectional rocking. Based on the experimental findings, improvements to the steel-steel armoured connection and joint details are proposed.

Introduction

There has been an increase in the use of precast concrete for structural components in buildings in india over the past 30 years. This is primarily due to precast element shaving high quality control, reduction in site form work,site possession time and a marked increased in speed of construction. Significant increases in the use of precast concrete in moment resisting frames and structural walls started in the mid to late 1980s. Today, precast seismic frames, walls, and flooring system have become the norm for use in buildings throughout india.

However, outside india, it has been reported that moment resisting frames and structural walls incorporating precast concrete elements have performed poorly in earthquakes (Hall, 1994;Wyllie and Filson, 1989). It is believed that the poor seismic performance in these precast frames and walls is due to brittle (non-ductile) behaviour of connection details between the precast concrete elements, inadequate detailing of components and outdated design concepts.

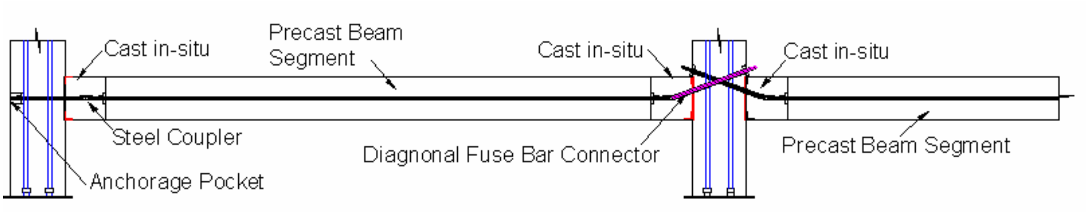
To ensure that adequate ductility may be achieved in structures, the capacity design for monolithic concrete structures was developed by india engineers and researchers and summarised in report by the india National Society for Earthquake Engineering in the 1970s (Park, 2002). The primary objective of the capacity design of structures for earthquake resistance is to ensure that the structure displays a dependable capacity to accommodate large earthquake imposed displacements and therefore prevent collapse even under severe earthquakes.

Theoretical Behaviour of a rocking Connection.

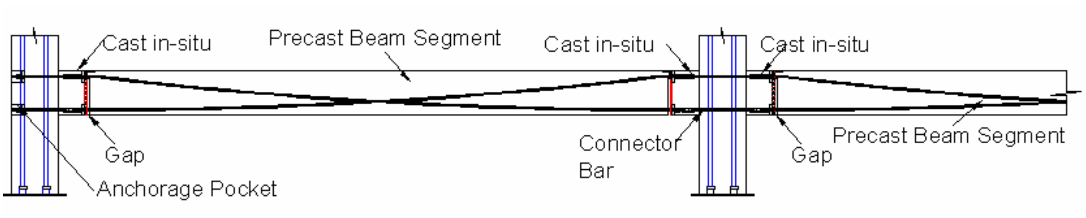
Five jointed precast seismic frames with different tend on profiles and connection details are proposed based on a seismic Damage Avoidance Design (DAD) philosophy. The pre cast beams and columns are designed elastically with the non- linear response of the systems provided by gap opening at the connection between the precast units. A steel-to-steel rocking connection is designed to protect the concrete from crushing. Steel angles are used as armour in the corners of the beam ends. The purpose of armouring is to confine the concrete and mitigate the high point force resulting from the rocking motion of the beam to column connection when the system is under seismic sideway. With only prestressing tendons, these jointed systems have limited energy dissipation capability therefore thread-bars are used to provide some supplementary energy dissipation to the frame. A theoretical model of the connection moment-rotation behaviour and lateral force-displacement response is proposed based onrigidbodykinematics.Theflagshapedhysteresisofthejointedframeisa combination of the nonlinear elastic behaviour of the tendon due to gap opening and the elasto-plastic behaviour of the supplemental energy dissipators. Also derived is a formulation of the maximum displacement (drift capacity) before re-centring is lost due to yielding of the tendon.

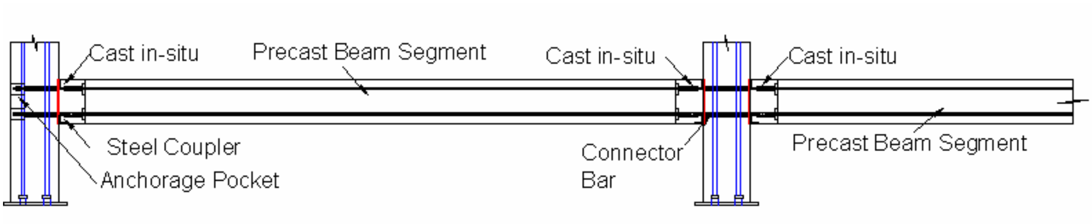
Proposed Design solution for armored jointed frames

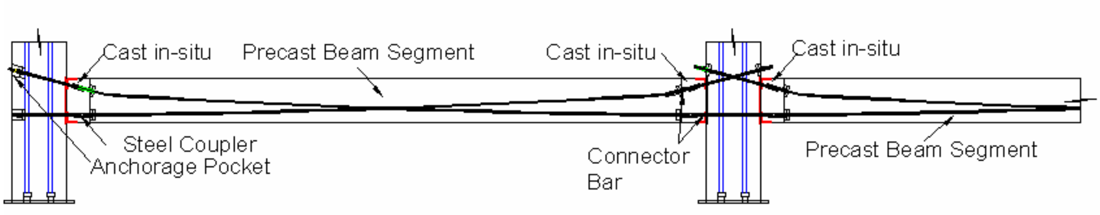
the seismic frame is made up of precast beam segment with straight tend on profile and diagonal fuse connectors. This allows the frame to not only carry lateral load but also balance a portion of gravity load. With adequate design, the ductile diagonal connector fuse-bars will protect the tendon from yielding. Damage is therefore restricted to the yielding of the external energy dissipators which can be easily replaced with minimum amount of labour and cost. Because each beam is connected to a column through a separate connector, each span can be stressed separately and provide extra redundancy in the unlikely case of prestressor anchorage failure. Adjustable beam-ends are cast in-situ at ends of each span allowing any variation on precast beam length to be accommodated. When loaded laterally, a gapat the beam to column interface next to the column face will open and stretch the unbonded tendons through the entire beam span This generates a high rocking force at top of the connection. In order to safely transfer this rocking force through the connection and into the precast beam segment, steel armour plates are cast in the beam ends and column faces respectively.

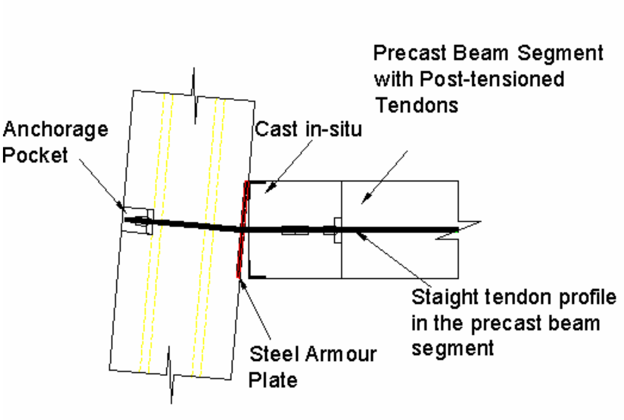


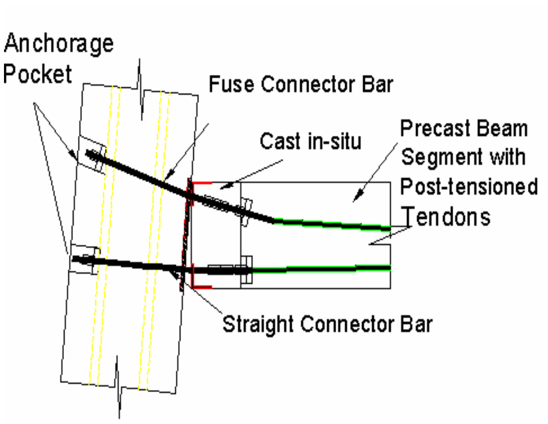
(a) Straight Tend on Solution with through joint diagonal fuse connectors









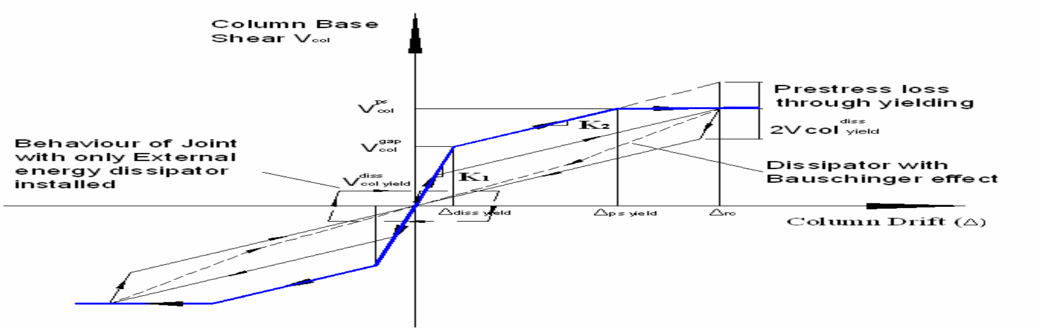


Design solution Evaluation

To evaluate the above proposed design solutions, push over curves of the interior beam to column joint from each different design solution are estimated as shown inFigure2-4 using concept developed by Arnold (2004) and Davies (2004). To allow rational comparison of the test results, all the properties such as tendons types and size, concrete strength, steel plate thickness beam and column cross section sizes of all the interior joints are fixed. A beam size of 400mmx560mm and column size of 700mmx700mm is used in all beams to column joints.Figure 2-4 showed that, design 3 and 4 have much lower initial stiffness than design 1, 2 and 5 because the partial gap introduced at either end of the precast beam segment. Through a rational analysis, it is found that the effective stiffness of partially gap beam is calculated to be only some 20% of the gross stiffness. Large frame displacement at low lateral force levels will cause damage to non-structure components such as windows and door lintel beams within the building. Despite the low initial stiffness, design 3 and 4 have the same lateral load capacity as of the design 1,2 and 5.

The “yield” drifts of all the interior joints are found to be 3.3%, 2.2%, 2.1%, 2.5%, 2.5% in Designs 1 to 5, respectively. The reason for this is because longer unbonded tendons are able to elongate more than the shorter tendons. In Design 1, diagonal fuse-bars connectors are inserted at an angle to couple together the tend on sin the beams to the column. Compared to Designs 2 and 3 in which straight through bolts bars are used to connect adjacent beam to columns, this increases the total tendon length in Design 1.Therefore, a higher yield drift level is expected in design solution 1. Design 4 and 5 have the same yield drift level as they have same tendon profile.

Theoretical cyclic load-displacement relationship of an unbonded post-tensioned



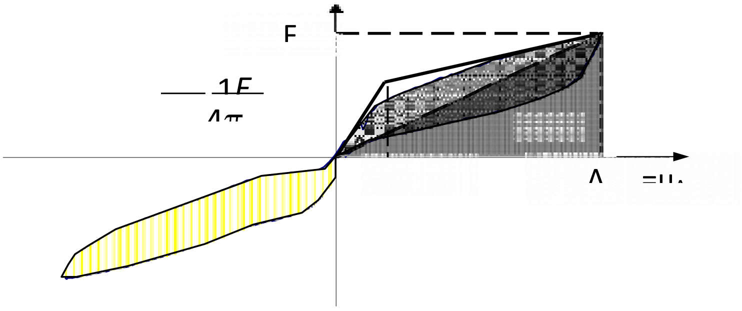


Figure8:Equivalent viscous damping.

Conclusion

Modelling concepts for a jointed beam to column connection designed from a Damage Avoidance Design point-of-view are presented. This involves the complete design and modelling of the beam joint details as well as supplemental energy dissipators. Damage in the joint is limited to the replaceable supplementary energy dissipators and fuse connector bars. The theoretical moment-rotation and lateral force behaviour of the jointed connection is also presented.

Based on these design concepts developed in this section on the jointed connections, five different jointed frame systems are proposed and theoretically evaluated. The theoretical force-displacement relationship of each of the five interior joint of the proposed frame systems is calculated, plotted and compared. In conclusion of this section the design solution with straight tendon and diagonal fuse connector bars (design solution 1) displays both higher initial stiffness and yield drift capacity among all five proposed frames.

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