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STUDY ON CONNECTION BETWEEN PRECAST CONCRETE BEAM AND CAST-IN-SITU COLUMN IN PREFABRICATED BUILDING FRAMES

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ABSTRACT

As a structural system prefabrication is very efficient in terms of cost, time and quality, but suffers a major setback in connection, which is an important design and construction factor. A mathematical model capable of analyzing multistoried building frames incorporating semi-rigid beam-column connections has been developed. The model is linear type and iterative in nature developed for multistoried building frames with connection, which is based on maximum end moment of frame. A mathematical relationship is developed and used for analysis and design of joints of a particular type. The linear moment-curvature (M-θ) relationship for this particular type of connection has been formulated by using elementary solid mechanics. Using this relationship investigations have been carried out to study the behavior of precast building frame such as connection flexibility and its effect on internal distribution of forces, lateral drift, joint rotation etc. A parametric study with the connection is also carried out. Finally a tentative recommendation regarding the use of the particular type of joint between precast beam and cast-in-situ column is made.

Keywords: Prefabrication, Beam-column connection, Building frame, moment-curvature.

INTRODUCTION

Structural prefabrication is a new construction procedure, which during the last few years has greatly enlarged the potentialities of reinforced concrete. It consists in building a complex structure by connecting prefabricated concrete elements, which collaborate to give structural strength to the whole. Moreover, prefabrication allows the use of elements of complicated shape without construction difficulties or expensive formwork, since each form is used to pour a large number of elements. The structural connection between elements is made by welding the reinforcing bars and pouring the joints with high-strength concrete- Old and new concrete elements may be bonded perfectly it the adjacent surfaces are roughened, drenched, and coated with cement plaster before the joints are poured. The weight and dimensions of prefabricated elements must be carefully considered in relation to the mechanical equipment available to lift them into position. Prefabrication usually requires much more accurate and detailed designing than is needed in the construction of a normal reinforced concrete structure.

PROBLEM IDENTIFICATION

The connection of the constituent members of precast construction plays an important role in affecting the behavior of the complete structure because the amount of moment-transfer is controlled by the joint characteristics. In the analysis and design of precast building frames, it is customary to represent joint behavior by an idealized model, either as a rigid joint or as a pinned joint. A number of experimental investigations have established that these two extreme assumptions are, strictly speaking, unattainable in practice. In reality most connections are semi-rigid in nature and possess some amount of rotational stiffness. Although precast semi-rigid construction is recognized by the codes and is economical, it has not become a viable type of construction due to lack of confidence about its behavior. No specific design procedure for precast construction has been recommended yet. In order to overcome these difficulties, an attempt has been made in the present study to develop a realistic mathematical model, which accounts for the connection flexibility effect in a prefabricated building frame.

The objectives of the study were:

- To gather a thorough knowledge about the precast multistoried building frames especially the linear behavior and design of connection under service load.
- To develop an appropriate mathematical model for the analysis of precast multistoried building frames incorporating the connection flexibility effects.
- To perform static analysis on the building frames changing various governing parameters of connection (number of bolts, plate thickness, stiffener size etc.) influencing the behavior of such frames.
- To investigate the distribution of internal forces in the members and the load-deflection behavior of the frame for different types of connection and loading conditions.
- To investigate the load-deflection behavior of the frame for different types of connection and loading conditions.

- To propose recommendations regarding use of the type of joint investigated in this study.

METHODOLOGY

Many types of beam-column connections have been developed to join the precast beam elements to column elements. The present study is intended with attention mainly to the beam-column connection of precast building structures, where the beam is precast, and the column is cast-in –situate beam is connected with a plate at the end which is also welded to the longitudinal reinforcement of the beam. The steel plate in column is welded to the dowel bars placed transversely in column (Figures-1a and b). After completing the casting of column in the ground floor, the beam that is manufactured in the plant, are then attached with column by the means of connection. Bolting the steel plate at the top and bottom portion of the beam to the plate of the column assembles these connections. Washer should be incorporated in the joint to avoid point contact and cracking of the concrete. It must be ensured that the detailing of connection provides full transfer of forces across the beam- column interface.

Figures-1a and b show the details of beam- column connection.

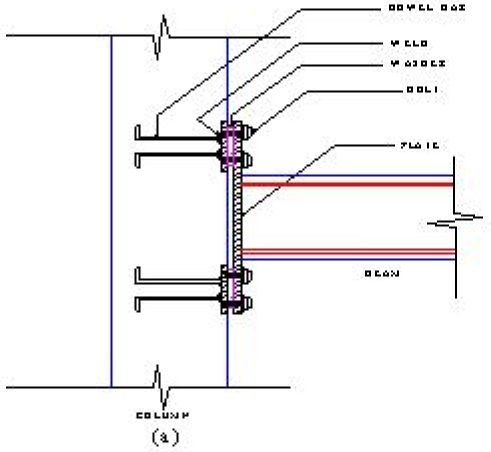

Figure-1a. Connection without stiffener between precast reinforced concrete beam and cast-in-situ column in prefabricated building frames.

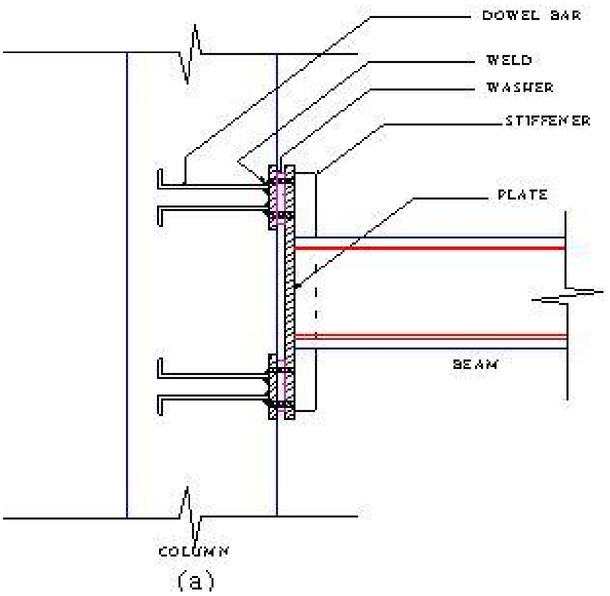

Figure-1b. Connection with stiffener between precast reinforced concrete beam and cast-in-situ column in prefabricated building frames.

MOMENT-ROTATION RELATION

The flexural connection behavior is represented by the moment rotation relationship, which relates the moment transmitted by the connection to the relative rotation of the connecting members. The moment-rotation curves for all type of connection are of non-linear type. In our study, we assume that moment-rotation curve is linear type. There are two ways that moment-rotation relationships in connection can be incorporated into structural analysis program.

- The moment-rotation information of every connection of every type can be stored.
- Since the moment-rotation characteristics for all connections of a given type are quite similar, a standardized moment-rotation relationship can be derived as function for the size parameters for that type of connection. Substituting its size parameter into the relationship can then generate the moment-rotation characteristics for a particular type of connection.

The later procedure is used in our analysis. The procedure involves the representation of the moment-rotation relation for all connection of a given type, are shown in the following form:

In order to develop a relation it is assumed that two rotational deformation components occur.

Type 1: Rotational deformation of connection due to Elongation of bolt.
Type 2: Rotational deformation of connection due to bending of the plate.

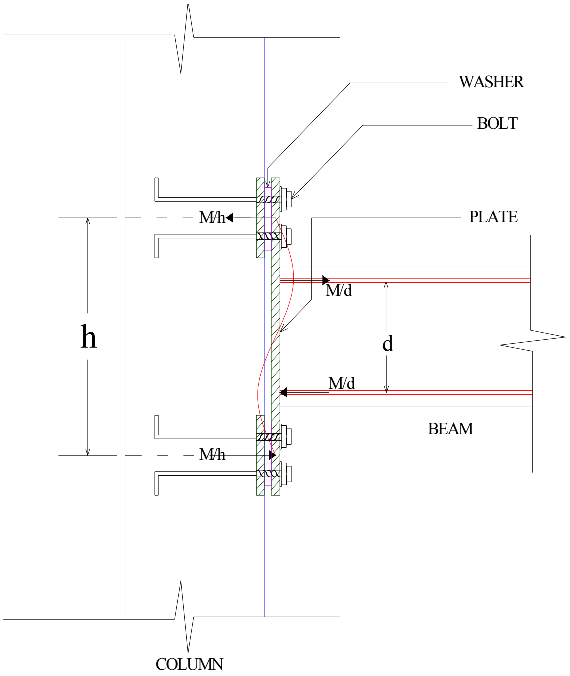

Figure-2. Rotation due to bending of the plate.

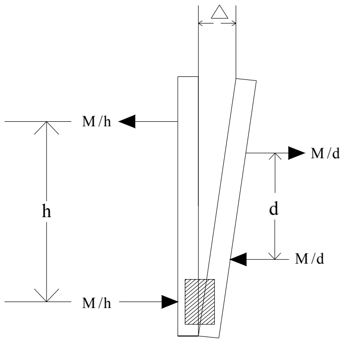

Figure-3. Elongation of bolt.

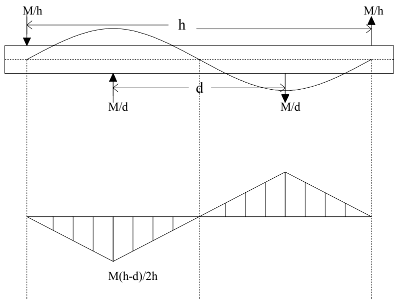

Figure-4. Rotational deformations due to bending of the plate.

Type-1

From Figure-3 due to elongation of bolt.

$$\Delta = \frac{M}{h}\frac{(t+t_w)}{N_b A_b E_s} \qquad A_b = \frac{M/h}{N_b f_{b,allow}} = \frac{\pi}{4} d_b{}^2$$

$$d_b = \sqrt{\frac{4M}{\pi h N_b f_{b,allow}}} \qquad \theta_1 = \frac{\Delta}{h} = \frac{4M(t+t_w)}{\pi N_b h^2 d_b^2 E_s}$$

Where

t = Thickness of plate t_w = Thickness of the washer

N_b = Total number of bolts
Es = Modulus of elasticity of steel d_b = Diameter of bolt
Δ = Elongation of bolt
M = Applied moment (kip-in) h = Moment arm
A_b = Area of single bolt f_b = Stresses of bolt
θ_1= Rotation due to elongation of bolt

Type- 2

Figure-4 shows the bending of the plate in precast beam and cast-in-situ column in prefabricated building frame. An idealized case, moment produces tension on the upper portion and compression on the lower portion of neutral axis. The bolt resists the tension developed by the top reinforcement and both bolt and compressive strength of the column concrete resist the compression developed by the bottom reinforcement. For simplicity of the analysis, the concrete contribution is neglected.

In order to determine the rotational deformation of plate without stiffener due to bending, the analytical approach is based on the area-moment method (Figure -4).

$$E_s I_{plate} \theta_2 = M\left[\frac{(h-d)^3}{12h^2} + \frac{d(h-d)(3h-2d)}{24h^2}\right]$$

$$\theta_2 = M\left[\frac{2(h-d)^3 + d(h-d)(3h-2d)}{24h^2 E_s I_{plate}}\right] \qquad \text{……(Eq. 1.1)}$$

So the total rotation is given by

$$\theta = \theta_1 + \theta_2 = M\left[\frac{4(t+t_w)}{\pi N_b h^2 d_b^2 E_s} + \frac{2(h-d)^3 + d(h-d)(3h-2d)}{24h^2 E_s I_{plate}}\right] \qquad \text{…..(Eq. 1.2)}$$

This is the M-θ relation of precast beam column joint. This relation makes the analysis to properly model and represent connection behavior. The slope of M-θ curve gives the stiffness of the joint.

Where

b = Width of the plate d = Effective depth of the beam
θ2 = Rotation due to bending of the plat
θ = Total rotation

$I_{plate} = \dfrac{bt^3}{12}$ = Moment of inertia of the plate

For plate with stiffener, Isp (the moment of inertia of stiffened plate) from Eq. 1.1 to Eq. 1.2 should replace Iplate

$$I_{sp} = (N_{br}+1)\left[\frac{t_s h_s^3}{12} + t_s h_s\left(\frac{h_s}{2} - \bar{y}\right)^2\right] + \frac{bt^3}{12} + bt\left(\frac{t}{2} + h_s - \bar{y}\right)^2$$

Where

$$\bar{y} = \frac{(N_{br}+1)t_s h_s \frac{h_s}{2} + bt\left(h_s + \frac{t}{2}\right)}{(N_{br}+1)t_s h_s + bt}$$

I_{sp} = Moment of inertia of stiffened plate
b = Width of column (width of plate)
$\sigma_{allowable}$ = Stress in plate t_s = Thickness of the stiffener
h_s = Height of the stiffener
N_{br} = Number of bolt in one row

In order to find the thickness of plate to resist applied moment, an iterative procedure is used which is as follows:

If $\bar{y}\rangle(t + h_s - \bar{y})$

$$I_{sp} = \frac{M(h-d)\bar{y}}{2h\sigma_{allow}}$$

$$\frac{bt^3}{12} = \left\{\frac{M(h-d)\bar{y}}{2h\sigma_{allow}} - (N_{br}+1)\left[\frac{t_s h_s^3}{12} + t_s h_s\left(\frac{h_s}{2} - \bar{y}\right)^2\right] - bt\left(\frac{t}{2} + h_s - \bar{y}\right)^2\right\}$$

Else $\bar{y}\langle(t + h_s - \bar{y})$

ANALYSIS REQUIREMENT

- The analysis is continued until the sway of the frame approaches of approximately H/400, the allowable deflection limit of a multistoried building.
- The positive moment does not exceed the allowable value corresponding to allowable stresses.

ANALYSIS PROCEDURE

The iterative solution procedure can be summarized separately stepwise as following:

- At the beginning, for each fixed end moment the number of bolt, plate thickness is selected.
- For this parameter the connection behavior is updated.
- The member end action is determined.
- At the same time, the positive moment and the lateral drift according to the requirement is checked.
- When the bolt, plate does not meet the requirement, the stiffener is used.
- If one of the requirements is not satisfied, the above steps are repeated using the latest connection stiffness.
- The convergence criteria are checked.

ETABS is used in our analysis for its relative ease of use, detailed documentation, flexibility and vastness of its capabilities. ETABS is one of the powerful and versatile packages available for specially building analysis. ETABS can be used for static analysis, modal analysis, harmonic analysis, and transient analysis, buckling analysis, response Spectrum analysis, time history analysis, push over analysis, p-delta analysis. ETABS has a comprehensive graphical user interface that gives the user easy interactive access to the program functions, commands, and document and reference material.

ANALYSIS AND PARAMETRIC STUDY

In this study a typical 10 storey 3 bay 2-D frames with span length of 20 ft and storey height 10 ft was analyzed to show the applicability of the mathematical model and also to arrive at some important conclusion regarding the effect of semi- rigid connection on multi-storied building frame. First the influencing parameters of the connection are identified and their effects on the behavior of the frames are investigated. A wide variety of connections, flexible to fairly rigid and perfectly rigid (fully restrained) are made from this parametric study. Using these types of connection several investigation are performed to observe the behavior of the frames under service load. The first investigation reveals the effect of semi-rigid connections on the behavior of frames. The distribution of forces in the members and lateral drift are studied and presented.

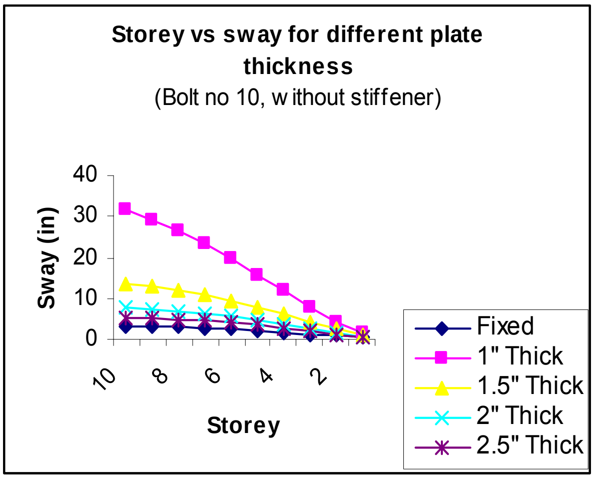

Figure-5. Storey vs. sway for different plate thickness.

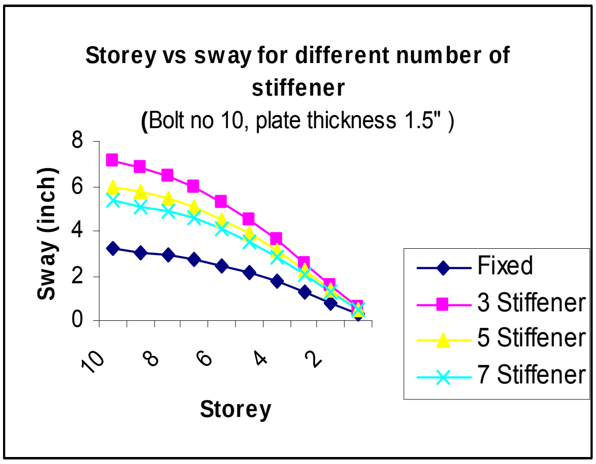

Fig-6. Storey vs. sway for different number of stiffener.

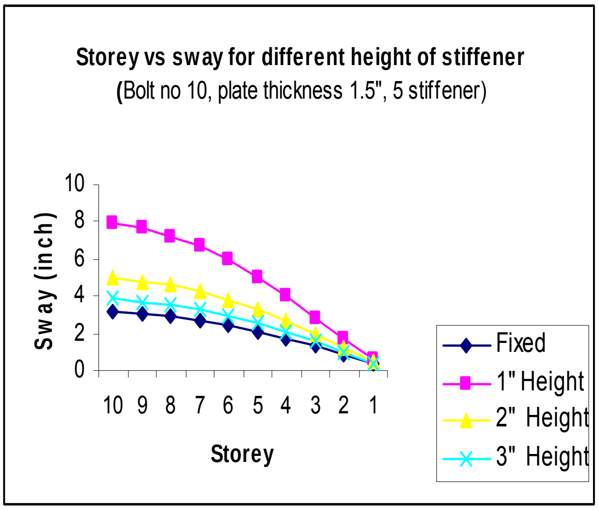

Fig-7. Storey vs. sway for different height of stiffener.

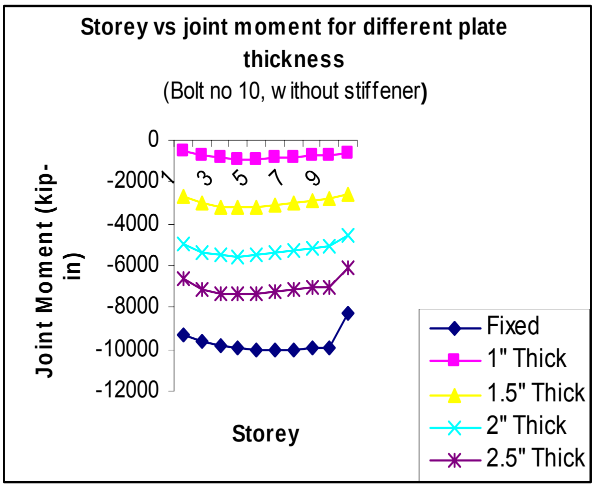

Fig-8. Storey vs. joint moment for different plate thickness.

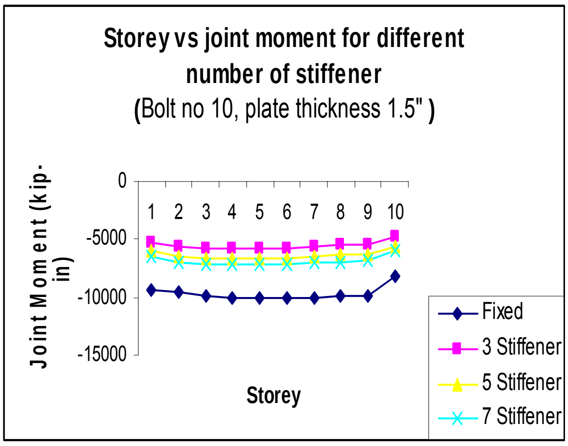

Fig-9. Storey vs. joint moment for different number of stiffener.

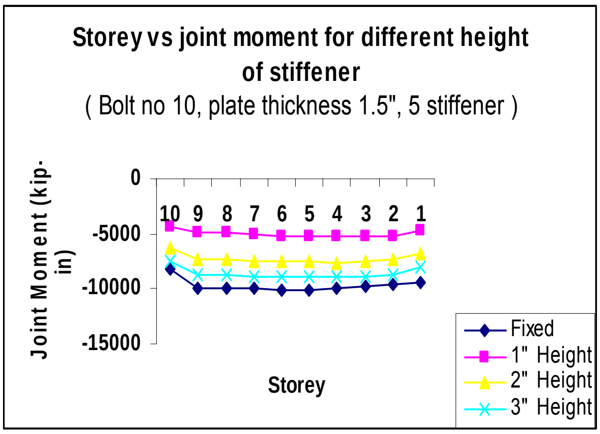

Fig-10. Storey vs. joint moment for different height of stiffener.

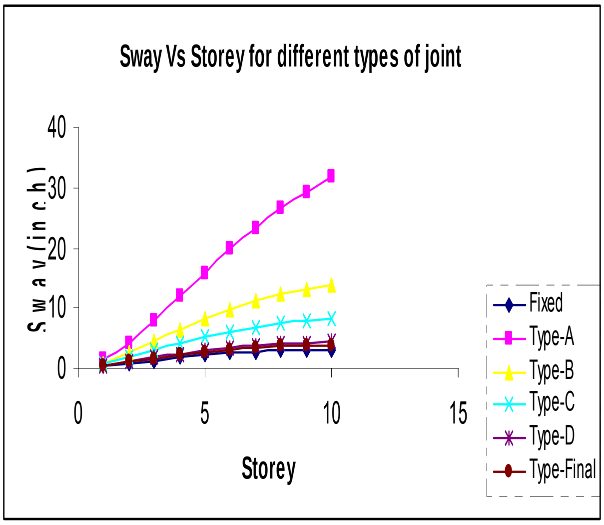

Fig-11. Storey vs. sway for different joint types.

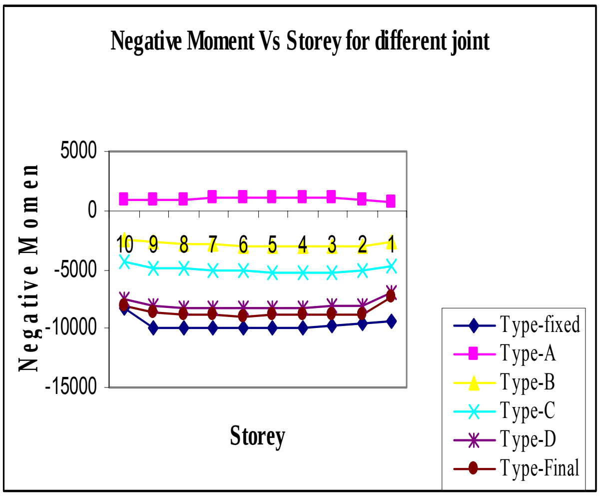

Fig-12. Storey vs. joint moment for different types of joint.

From Figure-5 it was found that with the increase of plate thickness the sway decreases but due to practical limitation the thickness cannot be varied indifferently. From Figure-6 it can be seen that with the increase of stiffener numbers the sway reduces drastically. Again it is not justified to use higher number of stiffener. From Figure-7 it was found that the height of stiffener has a marked impact on the sway. It is the principal parameter in controlling the sway. The connection with stiffener having a sufficient height can control the sway even more than the rigid frames. From Figure-8, with the increase of the plate thickness the joint moment also increases drastically. But due to practical limitation it is not possible to use thicker plate that gives us joint closely resemble to fixed, so we have to use stiffener. With the increase in stiffener (number and height) the joint moment increases significantly.

From the above parametric study we select five types of joints varying different parameters. The five types of connections are used here ranging from very flexible to nearly rigid. In addition a perfectly rigid connection is also included in the analysis, which is as follows:

Table-1. Joint type details

Joint type	**No. of bolt**	**Plate thickness (inch)**	**No. of stiffener**	**Stiffener height (inch)**
A	8	1.0	-	-
B	12	1.5	-	-
C	8	1.0	5	1.0
D	8	1.5	5	2.0
Final design	8	1.0	5	3.0

From Figure-11 it was found that Type A joint produces excessive sway on the frame, Type D develops sway near to the allowable limit and Type-Final gives desirable sway. For this reason, Type-Final was selected for connection design.

From Figure-12, we found for very flexible connection positive moment develops at a particular joint. With the increase of bolt number and plate thickness the negative moment arises at the joint but not a great deal to satisfy the requirement. But the use of stiffener the negative moment approaches closely to the nearly rigid and Type-Final gives desirable joint moment that approaches closely to the rigid joint.

CONCLUSION

- Plate thickness has the significant influence on the moment carrying capacity of connection and controlling sway of the frame.
- The increase in number of bolt has negligible impact on the behavior of the frame.
- Incorporation of the stiffener in a connection has a significant impact on moment carrying capacity and controlling sway. By increasing stiffener number and size, the moment and sway can be controlled within acceptable limits.
- Investigating the behavior of connection parameter finally a tentative recommendation regarding the use of the particular type of joint between precast beam and cast-in-situ column is made which approaches desirable sway and joint moment close to the rigid joint.

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