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A Comparative Study of Various Methods Involved in Design of Reinforced Concrete Beams with Web Openings

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ABSTRACT- A design problem involving design of beam with an opening has been solved as an explanation for the different methods. The design of beam with web openings is done from various methods like plasticity truss method, plastic hinge method, traditional design approach, IS code and AIJ method. After the designing part comparisons have been drawn between the various methods. These comparisons give a clear idea of the pros and cons of these methods. MATLAB as well as Microsoft Excel have been used as a programming tool.
It has been concluded that the Plasticity Truss Method provides a more conservative design approach than the Plastic Hinge Method. However the plasticity truss method requires more longitudinal reinforcement in the chord members as compared to the plastic hinge method. In this study, It has been calculated reinforcements for two beams with small opening and large opening respectively, under its ultimate load, for different longitudinal locations of the opening and different lengths of opening. The variations in area of steel have been recorded and explained for variations in these parameters. Two design methods, Traditional Design Method and Plasticity Truss Method, have been used for the beam with small opening, and compared. Beam with large opening has been designed using Plasticity Truss Method and ACI 318. This work also presents the comparison of reinforcements obtained in above case using IS456 and ACI 318. The results have been compared through graphs and possible reasons of difference in results of two theories have been mentioned. This study shows the reinforcement detailing required near the opening region of a beam, which focuses on crack control along with strengthening beam in flexure and shear.

KEYWORDS- Concrete beam, Mat lab, Plasticity, Truss, Web opening,

I. INTRODUCTION

The construction of new types of buildings necessitates the installation of a plethora of conduits and pipes to bring about the necessary infrastructure for running things like plumbing, air conditioning, electrical wiring, telephone lines, and computer networks. Figure 1 depicts a common perspective for seeing the lines used in the construction of a large building.[1]. These lines and channels are often put beneath the beam soffit and are then covered by a suspended roof to avoid any visual interference. The channels or lines might be as narrow as a few millimeters or as broad as a metre.

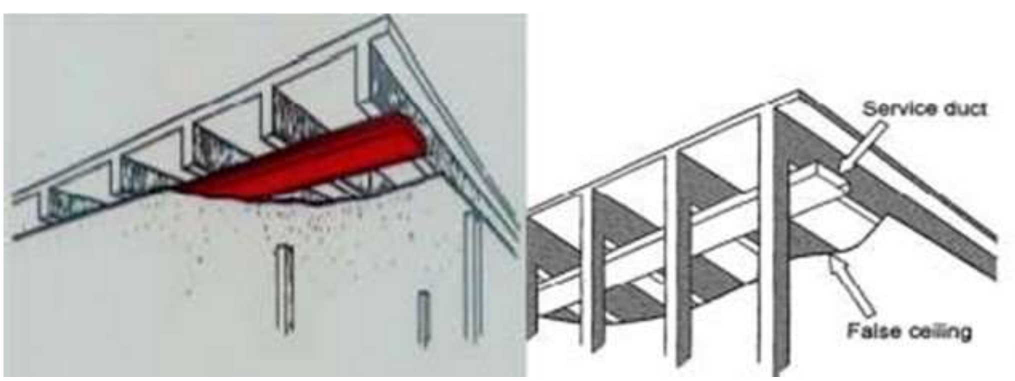

Figure 1: Typical layouts of service ducts and pipes

Pipes may be routed via crisscross gaps in the floor joist if desired. The services plan for the building shown in Figure 2 reduces headroom significantly and leads to a simpler layout overall. These savings can't be too significant in relation to the total cost of construction if the building is on the modest side.

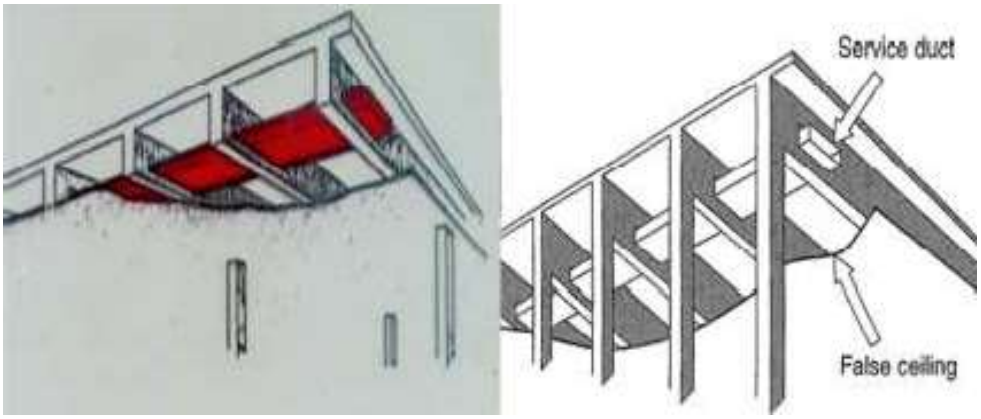

Figure 2: Alternative arrangements of service ducts and pipes

Due to the present economic situation and the rising tendency toward the utilization of frameworks as a way to manage building designs, structural designers are frequently required to retain arrangements for cross over gaps in the beams. As long as the entry is strengthened, most physicians don't mind if a few small pipes are put. Apertures in the floor are discussed at length in building codes of practice, but no definitive rules are laid forth. This leads to decisions being made based on instinct rather than evidence, which may have fatal results.

There is at least one documented event, described in (Merchant, 1967), in which the disillusionment of a massive edifice was diverted when significant agony at a massive gap in the stem of a shaft was discovered and eased in due time. The simple conduct of a shaft is obviously complicated by the inclusion of apertures in radiates. Because of the lower solidity of shaft, inner powers and minutes in a continuous pillar may need to be rearranged significantly, which may take a lot of time and cause an unneeded diversion under help strain. This bar's strength may be significantly weakened unless it receives substantial additional support beyond the norm.

Frame-Type Failure- The collapse of a frame is often caused by two separate diagonal fractures, one at each of the chord members located above and below the aperture.

A. Impacts of Forming Holes in Preexisting Beams

The prominent transverse gaps in the beams represent a possible weak point. On the other hand, this is not always the case. The M&E contractor is always asking for permission to drill a hole in the drywall of a brand new building so that they may run pipes through it and make the piping system more straightforward. It's challenging for the structural designer to make a judgement when asked to evaluate such demands. Although cutting a hole in the wall may save money for the building's owner, structural engineers will need to take a chance on the building's integrity and functionality if they do so[2].

When evaluating the stability of an older structure, it is sometimes necessary to remove concrete cores. However, non-shrink grout is often used to repair the cracks and holes. If the building must remain, the issue becomes whether or not such maintenance can fully restore the structure's previous level of safety and functionality.

II. ANALYTICAL DISCUSSION AND METHODOLOGY

A. Beams with Small Openings

Introduction to design approaches of small openings Methods for building RC beams with a range of aperture diameters are outlined in this article. Mansur and Tan propose a feasible threshold at which the aperture's depth (or diameter) is less than 40% of the whole depth of the beam (1999)[3]. This includes square, circular, and nearly square apertures. It's possible that the beam action is the primary driving factor here. As a result, beams with microscopic holes will be treated the same manner as solid beams throughout the design and analysis processes. However, apertures create stress concentration and early cracking in the immediate vicinity of the opening because they disturb the normal flow of stresses. Like any other discontinuity in the beam, an opening requires extra reinforcing at its periphery to prevent cracks from spreading too far and bringing down the structure too soon.

B. Traditional Design Approach

Evidence from tests was used to demonstrate this point using instances. Therefore, if the minimum depth of compression chord, hc, is more than or equal to the depth of ultimate compressive stress block, the existence of an opening has no effect on the beam's ultimate moment capacity, that is, when:

$hc \leq Asfy/0.85fcb$ (1.1)

where As = the area of flexural reinforcement,
fy = the yield strength of flexural reinforcement,
fc = the compressive strength of concrete and
b = the width of beam.

By introducing a tiny gap inside the reinforcing material in a shear-dominated area, as in the experiments performed by Salam (1977) [4], we can see that the beam may collapse in two different ways. The 3 Figure. The first kind, called a beam-type failure, is a frequent failure seen in solid beams, with one exception: when the failure plane is located in the exact centre of the aperture (as depicted in Figure 3.a).

Instead, the second kind of failure, called a frame-type failure, is caused by the development of two distinct diagonal fractures, one in each member connecting the two solid beam segments (as shown in Figure 3.b). It has been proposed that such setbacks need individual attention in order to achieve optimal design (Mansur and Tan 1999)[5].

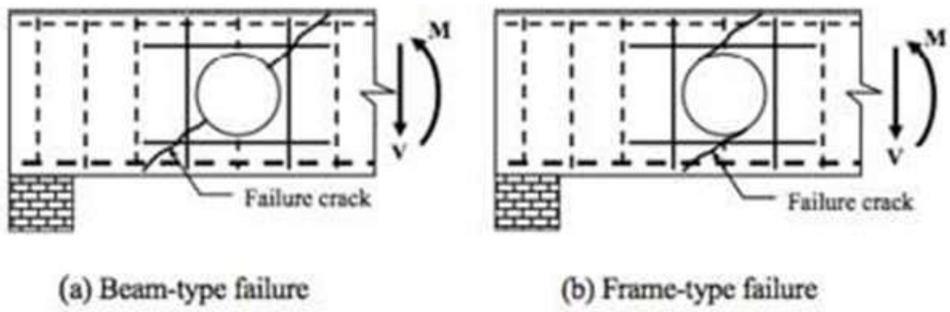

Figure 3: Small-opening shear failure modes

The traditional method of shear design works on the assumption that the nominal shear resistance, denoted by Vn, is directly proportional to the product of the shear modulus and the shear thickness.

Vn=Vc+Vs (1.2)

III. RESULTS AND DISCUSSIONS

A. Smallopening

As a percentage of the overall beam depth, the depth or diameter of the little aperture is less than 40%, which is a reasonable compromise[6]. Design and analysis of a beam with microscopic holes may, therefore, proceed in the same way as for a solid beam. Disruptions or breaks in the regular distribution of stresses are caused by the apertures provided. Results obtained from plasticity truss method and Traditional Design Method (w.r.t. Length of opening).

The results obtained from the Traditional Design Method are discussed in Table 1, and the comparison is shown with the aid of graphs. Table 4.1 provides details of reinforcement from the plasticity truss method in accordance with the American concrete institute (ACI) and the Indian standard (IS-456)[7], with the change in length of opening.

- Plots & their Possible Explanation (Plasticity Truss Method & Traditional DesignMethod)
- As the length of opening increases the Shear reinforcement also increases.
- The longer the aperture, the longer the chord must be, resulting in a smaller effective depth and more shear reinforcement.
- As length of opening increases the longitudinal steel increases slightly.
- This is because, as the span lengthens, the opening's centre shifts closer to the middle (left face of the opening has been fixed). If the opening's axis is unmovable, the longitudinal steel must be kept unchanged.
- As opening length increases Diagonal reinforcement increases slightly.
- Same as above.

Table 1: Reinforcement details obtained from Plasticity truss method with the change of length of opening

LENGTH	ACI			IS-456		
	Longitudinal Reinforcement	Diagonal Reinforcement	Shear Reinforcement	Longitudinal Reinforcement	Diagonal Reinforcement	Shear Reinforcement
0.15	1.52E+03	590.626	36.14	1.22E+03	372	60
0.2	1.56E+03	582.95	48.19	1.24E+03	372	80
0.25	1.60E+03	575.28	60.24	1.27E+03	372	100
0.3	1.64E+03	567.61	72.28	1.29E+03	372	120
0.35	1.68E+03	559.94	84.33	1.32E+03	372	140
0.4	1.73E+03	552.27	96.385	1.34E+03	372	160
0.45	1.77E+03	544.60	108.43	1.36E+03	372	180
0.5	1.81E+03	536.93	120.48	1.39E+03	372	200
0.55	1.86E+03	529.26	132.53	1.41E+03	372	220
0.6	1.90E+03	521.59	144.57	1.44E+03	372	240
0.65	1.95E+03	513.92	156.62	1.46E+03	372	260
0.7	2.00E+03	506.25	168.67	1.48E+03	372	280
0.75	2.05E+03	498.58	180.72	1.51E+03	372	300
0.8	2.10E+03	490.91	192.77	1.53E+03	372	320
0.85	2.15E+03	483.24	204.81	1.55E+03	372	340

0.9	2.20E+03	475.56	216.86	1.57E+03	372	360
0.95	2.26E+03	467.89	228.91	1.60E+03	372	380
1	2.32E+03	460.22	240.96	1.62E+03	372	400
1.05	2.38E+03	452.55	253.01	1.64E+03	372	420
1.1	2.45E+03	444.88	265.06	1.66E+03	372	440
1.15	2.52E+03	437.21	277.10	1.68E+03	372	460
1.2	2.60E+03	429.54	289.15	1.70E+03	372	480
1.25	2.69E+03	421.87	301.20	1.72E+03	372	500

Plots between area of reinforcement and length of opening according to different methods given following Plot (a) Plasticity Truss Method (ACI)

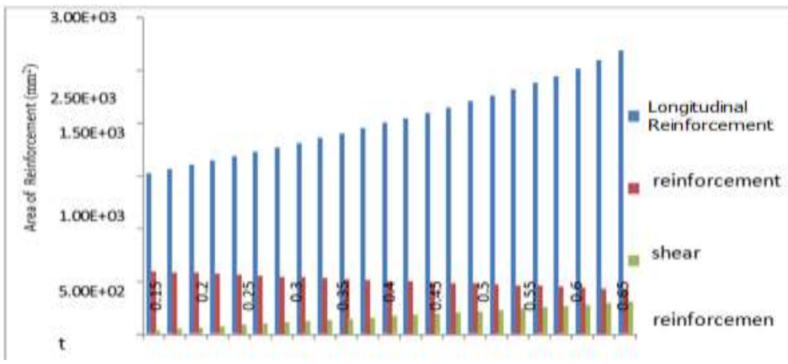

Figure 4: Area of reinforcement v/s length of opening PTM

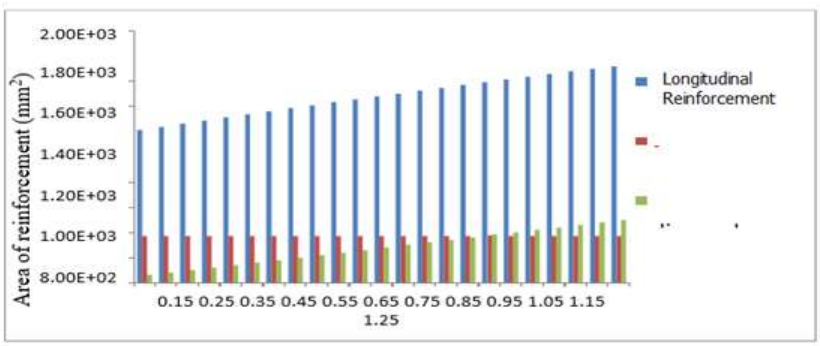

Figure 5: Area of reinforcement v/s length of opening PTM

B. Large Opening

The large openings are those that prevent beam-type behavior to develop. Thus, beams with small and large openings need separate treatments in design.

C. Comparison of Results

Plots & their Possible Explanation (plastic hinge method & plasticity truss method)

Plot of the reinforcements obtained from two methods, for differen locations of opening versus area of steel calculated is as under:

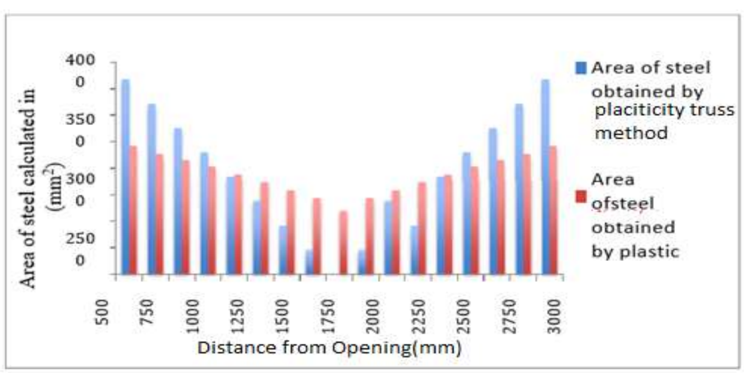

Figure 6: Distance from opening v/s area of steel calculated

Plot of the reinforcements obtained from two methods, for different locations of opening versus area of steel provided is as under:

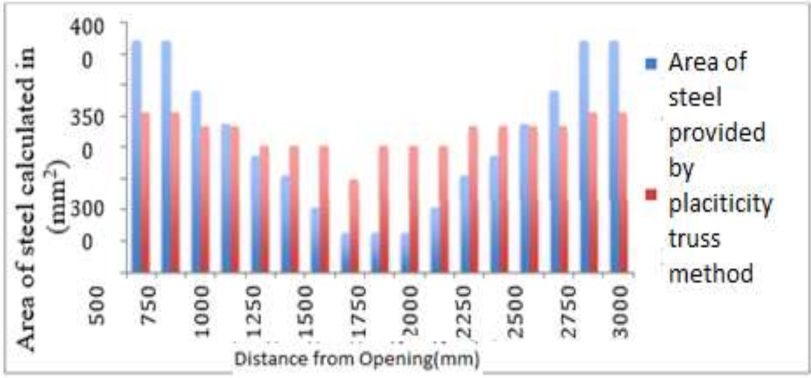

Figure 7: Distance from opening v/s area of steel provided

D. Longitudinal Reinforcement v/s Length of Opening

With increase in the length of opening, there is an increase in the longitudinal reinforcement required, in the chords above and below opening, which is shown in fig.7.

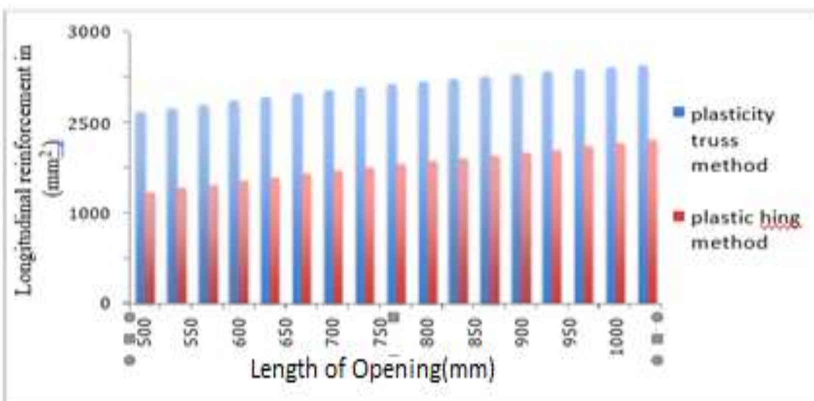

Figure 7: Length of opening v/s longitudinal reinforcement

E. Diagonal Reinforcement v/s Length of Opening

Diagonal reinforcement remains constant for different lengths of opening, which is shown in fig.8

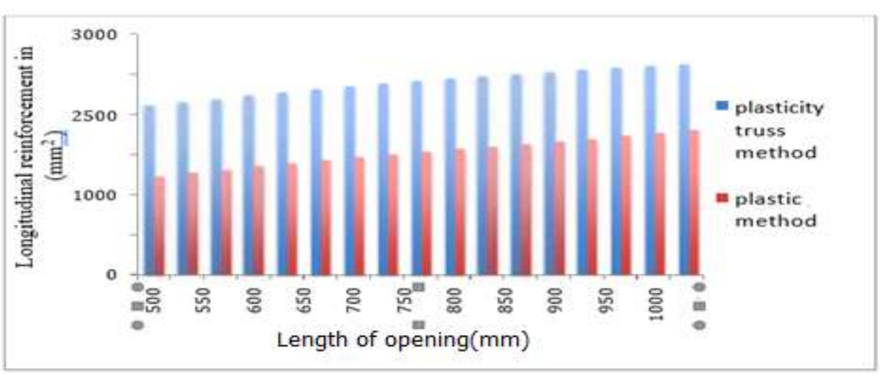

Figure 8: Diagonal reinforcement v/s length of open

IV. CONCLUSIONS AND FUTURE SCOPE

- Compared to the Plastic Hinge Method, the Plasticity Truss Method offers a more conservative design approach.
- More longitudinal reinforcing in the chord members is needed for the plasticity truss approach than is necessary for the plastic hinge method.
- Longitudinal reinforcement in the chords above and below the aperture must be increased as opening size increases.
- It's not a good idea to put apertures near the supports since they're high shear zones and need a lot of strengthening. There is a risk that this may cause a backlog of steel, which would impede the efficient placement of concrete.
- Diagonal reinforcement remains almost same
- Strength of beam is least affected with opening located at center of thebeam.

Future research directions are provided in light of the existing research gaps described below:

- Studying and implementing the use of Fibre Reinforced Polymer (FRP) material and steel plates to strengthen RC beams with openings is possible. That way, we can weigh the benefits and drawbacks of any material we utilize [10].
- Whether or whether it is acceptable to offer web opening, and which form of opening is more suited, may be determined by careful examination of the impacts of doing so in already-existing beams.
- Since there is a lack of data comparing the current methods used to construct RC beams with tiny apertures, future studies will need to do so based on a large number of experimental specimens.
- Future research should also compare the three plastic hinge systems presented and the plasticity methodology using a variety of experimental samples.
- It is necessary to examine the effects of various factors, including the steel plates, mechanical and geometrical qualities, and configurations, on the strengthening of RC beams using externally bonded steel plates.
- Externally bonded FRP materials, such as carbon fibre reinforced plastic (CFRP) sheets and fabric, glass fibre reinforced plastic (GFRP) sheets and fabric, and so on, may be used to reinforce RC beams, but their mechanical and geometrical properties and configurations must be considered.

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