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SHEAR WALL FRAME STRUCTURAL MEMBERS AND THEIR ANALYSIS FOR LATERAL LOAD

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Abstract:

The purpose of this study is to model and analyze the nonplanar shear wall assemblies of shear wall-frame structures. Two three dimensional models, for open and closed section shear wall assemblies, are developed. These models are based on conventional wide column analogy, in which a planar shear wall is replaced by an idealized frame structure consisting of a column and rigid beams located at floor levels. The rigid diaphragm floor assumption, which is widely used in the analysis of multistorey building structures, is also taken into consideration. The connections of the rigid beams are released against torsion in the model proposed for open section shear walls. For modelling closed section shear walls, in addition to this the torsional stiffness of the wide columns are adjusted by using a series of equations. Several shear wall-frame systems having different shapes of nonplanar shear wall assemblies are analyzed by static lateral load, response spectrum and time history methods where the proposed methods are used. The results of these analyses are compared with the results obtained by using common shear wall modelling techniques.

Key words: Shear Wall, Shear Wall-Frame Structures, Wide Column Analogy .

I. INTRODUCTION

The primary purpose of all kinds of structural systems used in the building type of structures is to support gravity loads. The most common loads resulting from the effect of gravity are dead load, live load and snow load. Besides these vertical loads, buildings are also subjected to lateral loads caused by wind, blasting or earthquake. Lateral loads can develop high stresses, produce sway movement or cause vibration Therefore, it is very important for the structure to have sufficient strength against vertical loads together with adequate stiffness to resist lateral forces.

In India, a considerable number of buildings have reinforced concrete structural systems. This is due to economic reasons. Reinforced concrete building structures can be classified as:

1. Structural Frame Systems: The structural system consists of frames. Floor slabs, beams and columns are the basic elements of the structural system. Such frames can carry gravity loads while providing adequate stiffness.

2. Structural Wall Systems: In this type of

structures, all the vertical members are made of structural walls, generally called shear walls.

Shear Wall–Frame Systems (Dual Systems): The system consists of reinforced concrete frames interacting with reinforced concrete shear walls. Most of the residential reinforced concrete building structures in India have shear wall-frame systems. A typical floor plan of a shear wall-frame building structure is given in Figure-1 It is a fact that shear walls have high lateral resistance. In a shear definition of FRC given by ACI Committee 544 is "fiber reinforced concrete is a concrete which is made of cement wall-frame system, this advantage can be used by placing shear walls at convenient locations in the plan of the building.

In general, shear walls are in planar form in the plan of the building. However, some combinations of planar walls are also used in the structural systems. Typical non-planar shear wall sections used in the building structures are given in Figure-2 The analysis of shear wall-frame structures is more complicated than frame systems. In order to reflect the actual behavior of the shear walls, several models have been developed. Wide column analogy, braced frame analogy and shell element derived by using finite element formulation are the most popular models. In the first two models, frame elements are used and in the last model, plane stress elements are used. Another important point for the lateral load analysis of building structures is modeling the structural system. A common method which is widely used in design offices is to perform analysis on a two dimensional model obtained from the actual three dimensional system by using some simplifying assumptions. The total number of degrees of freedom is reduced significantly through this method. Some computer programs which model the buildings in series of two dimensional frames in two orthogonal directions use the same logic. The displacement compatibility is established by infinitely rigid slabs at floor levels. However, this method, which is also called pseudo 3-D modelling, is not appropriate in lateral load analysis of some buildings, especially those having non-planar shear walls. Due to the complexity of the system, three dimensional analysis should be performed for such building structures. This is also valid for dynamic analysis of these kind of structures, so three dimensional analysis should be performed. In three dimensional analysis, there are some factors that influence how fast results can be obtained and how accurate they are. The two most important factors are the amount of required data and computer running time. These two should be optimized in such a way that sufficient results can be obtained by entering less data and having a relatively short computing time. The computer running time is mostly affected by the total number of degrees of freedom in the system. It can be decreased by

(a) A reduction in the total number of elements used in the analysis and

(b) The use of elements having less degree of freedom.

Frame element and shell element are the two basic structural elements used in the three dimensional analysis of structural systems. A general frame element has less total degrees of freedom when compared with a shell element. Modeling shear walls with frame members instead of shell elements can reduce the total degrees of freedom, which results a significant decrease in computer running time.

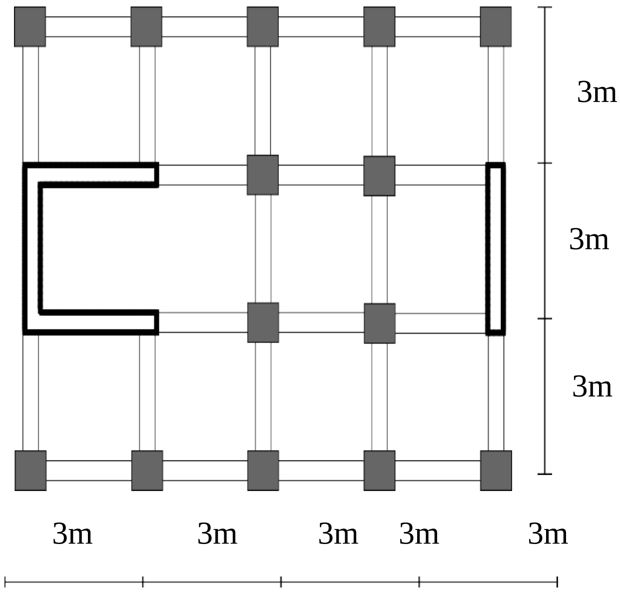

Fig. 1 Typical Floor Plan of a Shear Wall - Frame Building Structure

Shear wall

Shear walls are structural elements in addition to beam , slab and column. Shear wall is structural wall ,the strength and behavior of the walls will normally depend upon their geometry(H/L), slenderness ratio(.H/t), thinness ratio(L/T), material properties, and mode of disposition of steel, steel ratio in vertical and horizontal direction ,end condition. design of shear wall as a structural wall should be done as per clause of IS 13920 . For tall building it is necessary to provide adequate stiffness to resist the lateral loads caused by wind or earthquake, so that the deflection is within limit. In rectangular shear wall, structural walls around the elevators and stair wells and coupled structural walls they provide needed resistance to the lateral loads ,have ability to dampen vibration and keep the lateral drifts within limits, which reduces lateral sway of the building and often reduce the damage structure and their elements.

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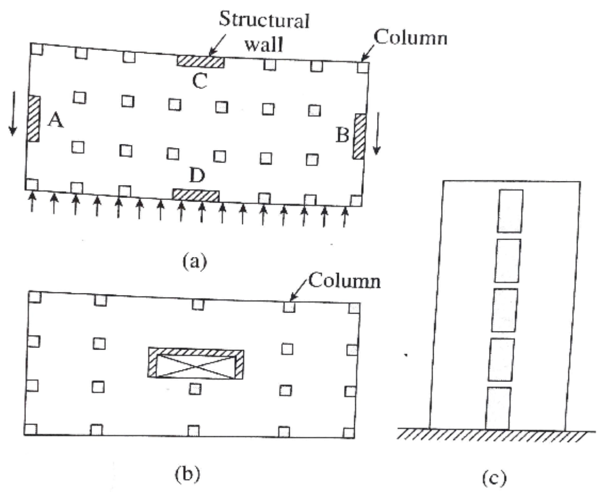


Types of structural walls (a) Rectangular shear walls (b) Structural wall around elevators and stairwells (c) Coupled structural walls

Fig.2

Advantages of shear wall in RCC structure

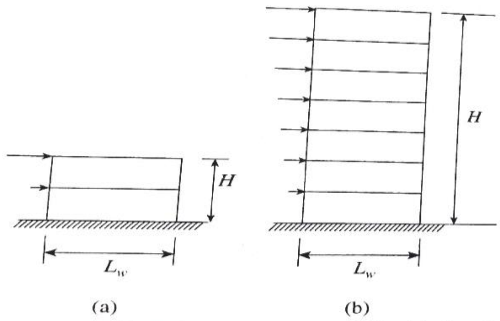
Shear walls have large strength and high stiffness and provide greater ductility than RRC. framed building structure. Based on observation of collapsed building during several earthquakes throughout the world it is evident that shear walls(structure walls) exhibits extremely good earthquake performance (FINTEL 1991).

Effects of shear walls

Shear walls must be provided symmetrically along the length and width of the building to avoid torsional stress and better performance the earthquake . If the wall is providing in only one direction , A proper moment resisting frame must be provided in the other direction. Structural walls should also be continuous throughout the height. It is to be noted that such an arrangement of walls in the interior of a building may not be as effective as the walls located on the periphery of the building , however because of the box shape they provide torsional resistance during earthquakes . in building it is not possible to use shear walls without some openings in them for doors, window, and service duct, such opening should be placed in one or more vertical and symmetrical rows in the walls throughout the height of the structure. The walls on either sides of opening are interconnected by short deep beams called coupling beams or link beams. Walls with opening arranged in a regular and rational pattern have very good energy dissipation characteristics.

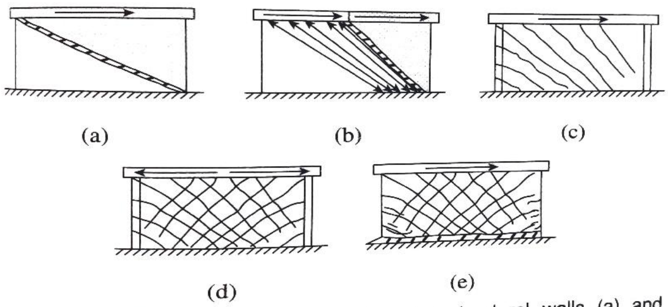
Classification of walls and their behavior

According to their geometry the walls may be classified as squat walls (H/L <2), intermediate walls (2<H/L<3), AND slender or cantilever walls (H/L>3). Squat walls are generally dominated by shear , whereas in slender walls lateral loads are resisted mainly by flexural action. When the value of H/L is between two and three , the walls exhibit a combination of shear and flexural behavior. Five basic modes of failure are possible in slender/ cantilever walls. The observed hysteretic behavior of well- detailed structural walls is similar to that of beams. However, shear deformation in the plastic hinge region of cantilever wall may be significantly larger than in other predominantly elastic region (Paulay and Priestley 1992). Squat walls are generally governed by their shear strength. They are usually subjected to high nominal shear stress .possible failure modes of a squat shear wall are in diagonal tension along a diagonal crack , diagonal compression and due to horizontal sliding shear (associated with low level of of axial loads and high levels of shear stress).



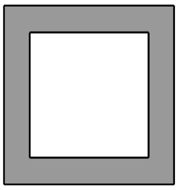
Classification based on H_w/L_w (a) Squat/ Intermediate wall (b) Cantilever wall

Fig.3

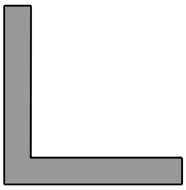


Shear failure modes of squat structural walls (a) and (b) Diagonal tension (c) and (d) Diagonal compression (e) Sliding shear

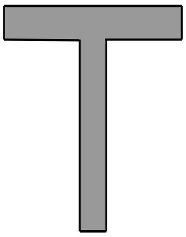
Fig.4



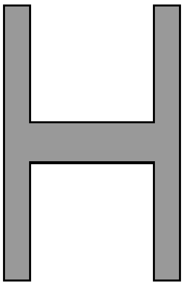
(a)Box Section



(b) L - Section



© T- section



(d) H-section

(d) W - Section

Fig.5 Typical Shear Wall Sections

II. Object and Scope of the Study

As stated previously, the majority of the residential building structures in India have shear wall-frame systems. Proper analysis and design of building structures that are subjected to static and dynamic loads is very important. Another important factor in the analysis of these systems is obtaining acceptable accuracy in the results. The object of this study is to model and analyze shear wall-frame structures having non-planar shear walls. In order to reduce the required time and capacity for the analysis of the structural systems, frame elements are used instead of plane stress elements in modelling the shear walls Two two-dimensional shear wall models, based on the conventional wide column analogy, are developed for modelling (a) open and (b) closed section non-planar shear walls The proposed models can be used in both static and dynamic elastic analysis of shear wall-frame structures.

III. MODELLING AND ANALYZING BUILDING STRUCTURES

The two most important factors in the analysis and design of building structures are choosing an appropriate structural modelling method which reflects the actual behavior of the system and deciding on the analyzing technique to be performed on the structure. In the first part of this chapter, a literature survey of the modelling techniques used in the analysis of structures is presented. These approaches can be divided into two parts: two dimensional modelling and three dimensional modelling. The most common analyzing techniques, equivalent lateral force method, modal superposition method and time history method.

Modelling Building Structures

As stated previously, forming a realistic mathematical model that reflects the actual behavior of the structural system is very important in analysis. In engineering practice, structural analysis of a reinforced concrete building is generally performed in the elastic range. However, in actual cases, the behavior of the structural system may be in the nonlinear range. This nonlinearity can be approximated and converted to a linear structural behavior by making a series of assumptions which simplify the problem significantly. Modelling techniques that are proposed in the literature for building structures can be investigated in two main groups as follows:

1. Modelling with a series of two dimensional systems.
2. Modelling with three dimensional systems.

Modelling Building Structures with a Series of Two Dimensional Systems

There are several methods that reduce the three dimensional building structure to a two dimensional system. In this part, the most common approaches that are often cited in the literature are presented. The most widely applied technique for two dimensional modelling is connecting all bents of the structure at storey levels by rigid links, which simulate the in-plane rigidity of the floors. The lateral deflections of columns and shear walls can be defined in terms of the slab's horizontal translation and this allows the possibility of representing a three dimensional structure by a two dimensional model. An example of a two dimensional model of a building structure is given in Figure -3. In Figure-3, it can be observed from the floor plan of the building that there is a symmetry in the loading direction. In addition to this symmetry in the plan, the resultant of the distributed lateral load, *w*, is axisymmetric due to the floor plan. In view of these conditions, no floor torsion takes place and the structure undergoes simple translation only. In the model, two repeated units (Unit 1 and Unit 2) are connected by rigid links at floor levels and half of the total load, *w*, is applied to the system. In this method, beams and columns are modelled by two dimensional frame elements, which have three degrees of freedom at each end. A typical two dimensional frame element is shown in Figure-4. Shear walls in the structural system are modeled by one of the methods mentioned . The stiffness method may be used to solve the reduced system. This technique may be applied only to structures that do not twist, since the forces in the vertical and horizontal members of the structure obtained after analysis do not depend on their locations in the plan of the building. In other words, in the model, the torsional effect of lateral loading is not taken into consideration.

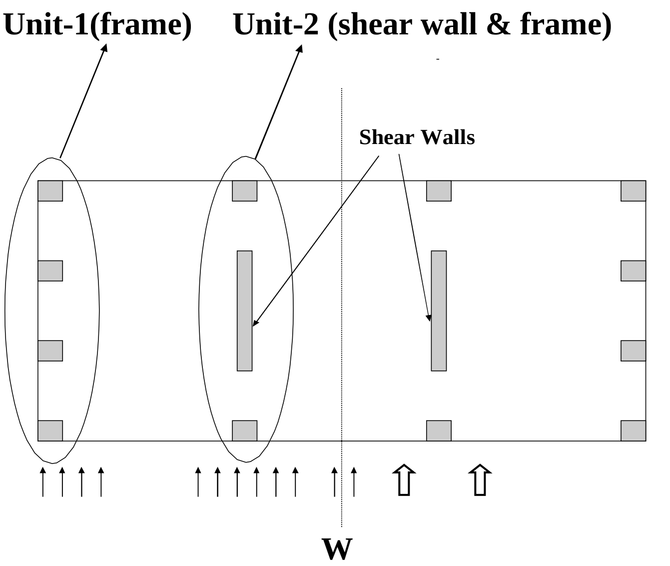


Fig.6 Two Dimensional Model of a Building Structure

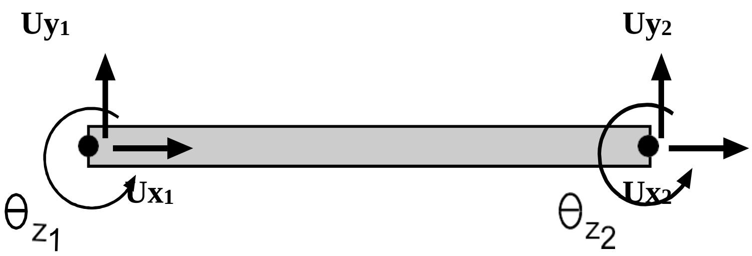


Fig. 7 A Typical Two Dimensional Frame Element

Their proposed method starts with locating an arbitrary origin at the left of and be- low the lower left-end corner of structural plan. Then, a two dimensional model is formed by assembling all bents in the same plane with the x–direction bents in one group and y-direction bents in the other. Next, a set of governing nodes, which are constrained against vertical displacements, is established in the model. These govern- ing nodes are connected to their corresponding floor level nodes by rigid vertical links, which have rotational releases at the floor level nodes. The lateral load acting on a storey is transformed into a lateral axisymmetric load and a torque acting at the origin of the storey. The governing nodes are used to apply this lateral force and torque for each bent. The reduced system can be solved using a computer program based on the stiffness method.

In the same study, another method was introduced in which, instead of separate sets of governing nodes, only a single set is used for all bents of the structure. This con- densed model gives the same results as the previous one, but it reduces the computer storage and running time. An example of the condensed two dimensional model of a building structure is given in Figure. In another study by the same authors, the performance of their proposed method in the dynamic analysis of building structures was investigated. These two models are effective in the analysis of structures having planar walls that translate and twist, but the application of the models on buildings having nonplanar shear walls with different shapes (L, U, etc.) may give incorrect results. The conventional continuum approach, which is based on the closed form solution of the characteristic differential equation of the structural system,

Modelling Building Structures by Three Dimensional Systems

In a typical three dimensional system, the frame elements that are used in modeling beams and columns have six degrees of freedom per node: three translations and three rotations. An example of a three dimensional frame member is given in Figure.
If the building structure has shear walls, probably a mesh of rectangular plane stress elements having six degrees of freedom at every corner should be used for modeling each single shear wall (a typical rectangular plane stress element having 24 degrees of freedom is shown in Figure 2.5). If the whole system is considered, there will be too many unknowns and a large system of equations would have to be solved in order to obtain results from such an analysis. Several methods and computer programs have been developed for the analysis of building systems in which the total number of unknowns are reduced by some assumptions. In addition to these methods, generalized 3D computer programs are also available. In this section, a review of these methods and computer programs that model the building structures using three dimensional systems is reviewed.

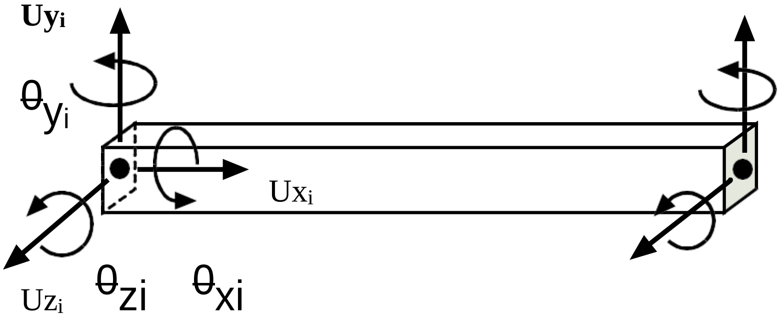


Fig.8 A Typical Three Dimensional Frame Element

MODELLING OF SHEAR WALLS

According to Turkish Earthquake Code, a shear wall is defined as a vertical structural member having a length of seven or more times greater than its thickness. Being the major lateral load resistant units in multistorey building structures, shear walls have been studied experimentally and theoretically over the last fifty years. In the lateral load analysis of building structures having shear walls, proper methods should be used for modelling planar and nonplanar shear wall assemblies. Shear wall models in the literature can be divided into two:

1. Models developed for elastic analysis of building structures.
2. Models developed for nonlinear analysis of building structures.

The investigation of nonlinear shear wall models is beyond the scope of this study. Examples of such models can be found in. In this chapter, shear wall models developed for the lateral load analysis of multistory structures in elastic region are presented. Since the methods for modeling building structures are analyzed separately (two dimensional modelling and three dimensional modelling are presented. shear wall modelling studies can also be investigated in according to the two and three dimensional approaches.

Two Dimensional (Planar) Shear Wall Models

The literature mentions several shear wall models that were developed for two dimensional elastic analysis of multistorey building structures. In this part, a review of these models is given.

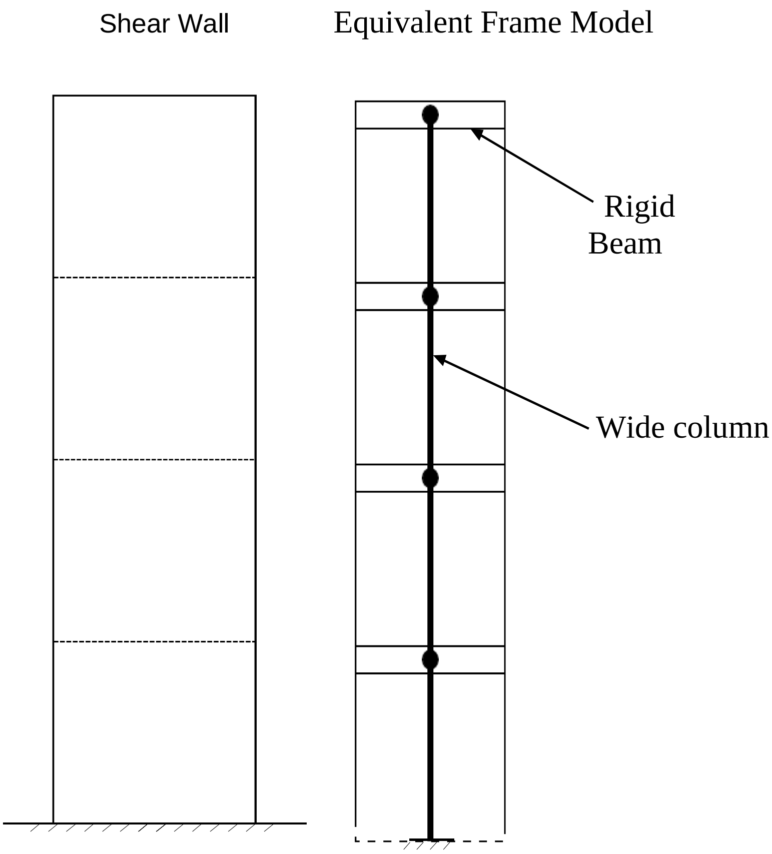


Fig.9 Equivalent Frame Model of a Shear Wall

Equivalent Frame Model (Wide Column Analogy)

The equivalent frame model was developed by Clough et al. , Candy and MacLeod for the analysis of plane coupled shear wall structures. The model was limited to lateral load analysis of rectangular building frames without torsion. It was improved in the 1970's by Mcleod and McLeod and Hosny for the analysis of nonplanar shear walls. In the equivalent frame method, which is also known as wide column analogy, each shear wall is replaced by an idealized frame structure consisting of a column and rigid beams located at floor levels. The column is placed at the wall's centroidal axis and assigned to have the wall's inertia and axial area. The rigid beams that join the column to the connecting beams are located at each framing level. A sample model is shown in Figure 3.1. In this method, the axial area and inertia values of rigid arms are assigned very large values compared to other frame elements. Due to its simplicity, the equivalent frame method is especially popular in design offices for the analysis of multistorey shear wall-frame structures.

Shear Wall Models for Three Dimensional Analysis

Shear wall models used in the three dimensional analysis of structures are generally the modified versions of two dimensional models. In the following pages, the most common of these models are reviewed.

Equivalent Frame Model

A two dimensional (planar) equivalent frame model is used by many as a three dimensional model especially for the analysis of tall buildings having reinforced concrete cores. MacLeod , MacLeod and Hosny and Lew and Narow studied the equivalent frame model for the analysis of shear wall cores of tall buildings. Ghuneim and Dikmen used the equivalent frame model in the three dimensional analysis of tunnel form buildings. The model is identical to the two dimensional equivalent frame with the additional requirement of the vertical compatibility of the intersecting walls. In Figures. a triangular reinforced concrete core and its equivalent frame model are shown Smith and Girgis determined that the conventional wide column model has some deficiencies, especially in analyzing closed or partially closed core walls subjected to torsion. They reported that when these type of walls are subjected to shear stresses, the column elements used to model the walls are afflicted by parasitic moments. Due to this, in a closed or partially closed section core modelled by wide column analogy, relatively high values are obtained in shear deformations and rotations when compared with finite element modelling. Kwan also stated the sources of errors in the application of wide column analogy to the three dimensional analysis

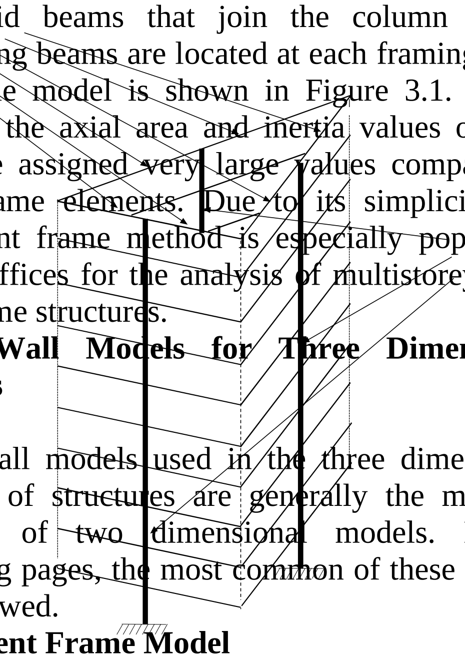


Fig.10 Equivalent Frame Model of a Triangular Core

IV. CONCLUSION

In the lateral load analysis of shear wall-frame structures, a fundamental goal is to model the shear wall assemblies using a realistic and feasible method. Modelling and analysis of symmetric building structures having planar shear walls in two dimensionsmay be a practical solution. However, especially for asymmetric shear wall-frame building structures, which have nonplanar shear wall assemblies, modelling and analysis studies should be in three dimensions. Three dimensional analysis of shear wall-frame structures may not be feasible for the cases in which the shear wall assemblies are modelled using a large number of plane stress elements. A reasonable method should be used in modelling such building structures. In this study, three dimensional modelling of nonplanar shear wall assemblies of shear wall-frame structures is investigated. Modelling techniques and methods that are used in analysis of such building structures are presented. common methods for two and three dimensional modelling of nonplanar shear wall assemblies are reviewed. The proposed nonplanar shear wall models for (a) open sections and (b) closed sections are presented. The results of the verification studies on the proposed models are given in. The proposed shear wall models are based on the conventional wide column analogy and they can be used effectively in the analysis of multistorey building structures where rigid diaphragm floor assumption is valid. The model for open section shear wall assemblies consists of wide columns located at the middle of the planar shear wall units between two floor levels. These wide columns have the same stiffness properties as the planar shear wall units. Rigid beams are located at the floor levels of 122 the building structure and the connections between the perpendicular rigid beams are released against torsion, which prevents the transfer of torsional moments. As a result, the additional torsional stiffness of the rigid beams is removed from the structural system. Similar to the open section model, the model proposed for closed section shear wall assemblies consists of wide columns and rigid beams. In addition to releasing torsional moments at the rigid beam connections, the torsional stiffness of the wide columns of the model are adjusted in such a way that the torsional stiffness of the closed section and the sum of the torsional stiffness of the wide columns are equivalent.

The performance of the proposed models is checked by

(a) Equivalent lateral load analysis,

(b) Response spectrum analysis and

(c) Time history analysis

of several sample shear wall-frame building structures having different shapes of shear wall assemblies. The results of the analyses, in which the proposed models are used, are compared with the results obtained using SAP shell elements and ETABS wall elements. Good agreement with the models using SAP shell elements was obtained in both static and dynamic analyses. The validity of the proposed models was also investigated by considering a number of structures studied by several authors. The analysis results obtained by using the proposed models agree well with those in the literature. In view of the comparisons summarized above, the proposed methods can be used in modelling nonplanar shear wall assemblies of shear wall-frame structures where the rigid diaphragm floor assumption is valid. Displacement and resultant force values obtained by using the proposed models have an average relative difference of 6% with the results obtained using SAP2000 shell elements. If the time spent on forming a building model is considered, using the proposed models in modelling nonplanar shear wall assemblies is less time consuming when compared with the models in which plane stress elements are used. The total running time of the computer in analyzing the building structures is also an important issue.

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