Dynamic Evaluation of Lateral Force Resisting Systems for Tall Buildings

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***Abstract* - In recent years construction of high rise building is widely increased due to highly increasing cost of land and scarcity of land in metropolitan cities. These structures are sensitive to wind and earthquake forces. Behavior of such structures can be controlled by effective lateral structural systems, which increases stiffness of building. Although in present days computer technology allows for precise analysis and design of different systems for high rise buildings, it does not readily insight for choosing among the alternatives of these systems to arrive at the best overall design. While studying uncontrolled response it was observed that response in terms of displacement and acceleration was exceeding IS code limits. The enhancement in the performance of the building is studied under earthquake loads by installing lateral force resisting systems, such as bracing system and steel plate shear walls. These systems were applied at various positions with different cross-sectional properties. Modeling and analysis was carried out using ETAB 14. It is evident from the observations that all the proposed arrangements improve the performance of the building in controlling storey displacements, accelerations as well as drift. The present work is expected to accelerate the implementation of steel plate shear walls as a lateral force resisting systems to earthquake excited tall slender buildings.**

Index Terms - Tall building, Steel plate shear wall, Bracing system, Shear Wall, Lateral Forces, E-Tab 14
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I. INTRODUCTION

A. General:

Amongst the natural hazards, earthquakes have the potential for causing the greatest damages. Since earthquake forces are random in nature & unpredictable, the engineering tools needs to be sharpened for analyzing structures under the action of these forces. Earthquake loads are to be carefully modelled so as to assess the real behaviour of structure with a clear understanding that damage is expected but it should be regulated. In this context time history and response spectra analysis which is an iterative procedure shall be looked upon as an alternative for the orthodox analysis procedure.

Population explosion has made high-rises the order of the day as it is only logical solution and way of accommodating growing population within the boundaries of cities. It is needless to emphasise that tall buildings are prone to larger movement and damages than low rise structures during earthquakes and as the number of people occupying in high rise building at any given time is far greater so also the risk of collateral damage. Apart from ensuring structural safety during earthquakes high rise are giving engineer another cause of concern that is mitigation of wind induced vibrations that cause occupant discomfort. Excessive floor displacements and accelerations which are caused by relatively frequent strong ground motions can render building unserviceable for reasons for occupant discomfort. The effect is more pronounced in tall and slender buildings and for buildings to qualify for serviceability. The dynamic response of structures to earthquakes needs to be reduced.

In general, the structural system of building is a complex three dimensional assemblage of various combinations of interconnected structural elements. The primary function of structural system is to carry dynamic and static loads, wind loads, external or internal explosion and impact loads. A variety of factors has to be considered in the process of selecting most suitable structural system for high rise building. The selection is complicated process, and no simple clear cut process available. The design team must use every available means, such as imagination, previous experience, and relevant literature to arrive at the best possible solution in each particular case. Although present day engineering computer technology allows for precise analysis and design of different systems of high rise building, it does not provide readily insight for choosing among alternative of these systems to arrive at the best overall design.

B. Objective:

1. Study of conventional lateral force resisting systems for tall building and various factors affecting on these systems.
2. To study the response of building for conventional lateral force resisting systems.
3. Use of SPSWs as a lateral force resisting system in tall buildings.
4. Compare the results between bracing system and SPSWs for various performance criteria.
5. To compare the dynamic response quantities for different structural systems.

6. To decide most efficient lateral force resisting system for tall buildings.

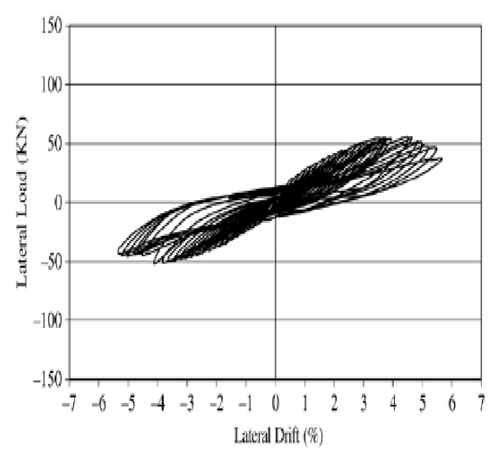
II. LITERATURE REVIEW

On Oct. 17, 1989, a tall, steel-framed, San Francisco office building with 47 above-grade stories was excited by the Loma Prieta earthquake. The building response was recorded by accelerometers maintained by the California Division of Mines and Geology Strong Motion Instrumentation Program. From the records, important characteristics of the building response can be identified. In this paper, a computationally efficient, approximate dynamic analysis of the building conducted. By making use of the repetitive nature of the lattice framing system, finite-element models generated using continuum methodology have significantly fewer degrees of freedom than models generated using classical discrete finite element techniques. The vibration characteristics of the continuum model, as well as the results of the dynamic analysis, are compared to the building's recorded response. The continuum model is accurate in capturing the dominant periods of vibration as well as the time history response and shows promise as a tool for preliminary design of large lattice structures.[1]

This paper describes an experimental study on the seismic performance of concentrically braced steel frames made with cold-formed rectangular tubular bracing members. A total of 24 quasistatic cyclic tests were performed on full size X bracing and single diagonal bracing systems. Two loading sequences were considered: a symmetrical stepwise increasing deformation sequence and a displacement history obtained from nonlinear dynamic analyses of typical braced steel frames. All specimens buckled out-of the plane of the frame and the tests were interrupted when fracture of the braces occurred in the region of highest curvature. For X bracing, the results clearly show that the effective length of the braces can be used to determine their compression strength and to characterize their hysteretic response, including energy dissipation capability. Simplified models are proposed to predict the out-of-plane deformation of the braces as a function of the ductility level. These models are then used to develop an empirical expression to assess the inelastic deformation capacity before fracture of bracing members made of rectangular hollow sections. Brace slenderness ratio can be reduced by adopting an X bracing configuration, it is shown that tension acting bracing can provide an efficient support at the brace intersection point for compression bracing (k=0.5). Rectangular hallow section are very effective in compression and their use in X bracing forms an efficient means of resisting lateral seismic load.[2]

Braced frames and steel plate shear walls (SPSWs) have both been shown to be useful in the seismic retrofit of buildings. While both these systems have merit, no guidance exists to help the engineer determine which of the two approaches is preferable in terms of providing stiffness, maximum displacement ductility, cumulative hysteretic energy dissipation, and energy dissipation per cycle for a given strength. In an attempt to provide some quantitative data and insight for this purpose, this paper describes and compares the results from cyclic testing of six frames: four concentrically braced frames, and two light-gauge steel plate shear walls. The largest initial stiffness was provided by a braced frame specimen with cold formed steel studs and the largest ductility was achieved with a steel plate shear wall with flat infill. After scaling the hysteretic results to the same design base shear, it was found that both the energy dissipated per cycle and the cumulative energy dissipation were similar for flat plate SPSW and braced frames with two tubular braces, up to a ductility of four. After that the tubular braces fractured while the SPSW with a flat infill reached a ductility of nine before the energy dissipation per cycle decreased.[3]

Steel bracing has proven to be one of the most effective systems in resisting lateral loads. Although its use to upgrade the lateral load capacity of existing Reinforced Concrete (RC) frames has been the subject of numerous studies, guidelines for its use in newly constructed RC frames still need to be developed. In this paper, the efficiency of using braced RC frames is experimentally evaluated. Two cyclic loading tests were conducted on a moment frame and a braced frame. The moment frame was designed and detailed according to current seismic codes. A rational design methodology was adopted to design the braced frame including the connections between the brace members and the concrete frame. Test results showed that the braced frame resisted higher lateral loads than the moment frame and provided adequate ductility. The adopted methodology for designing the braced frame resulted in an acceptable seismic performance and thus represents the first step in the development of design guidelines for this type of frames.[4]



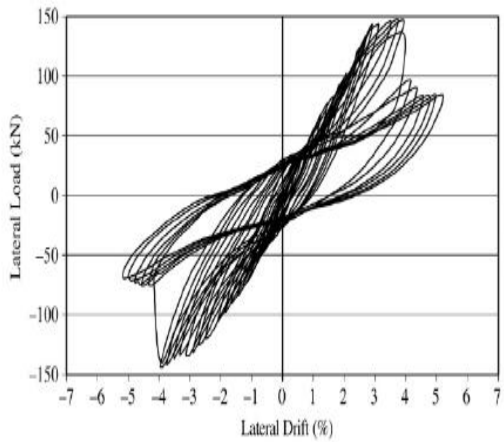


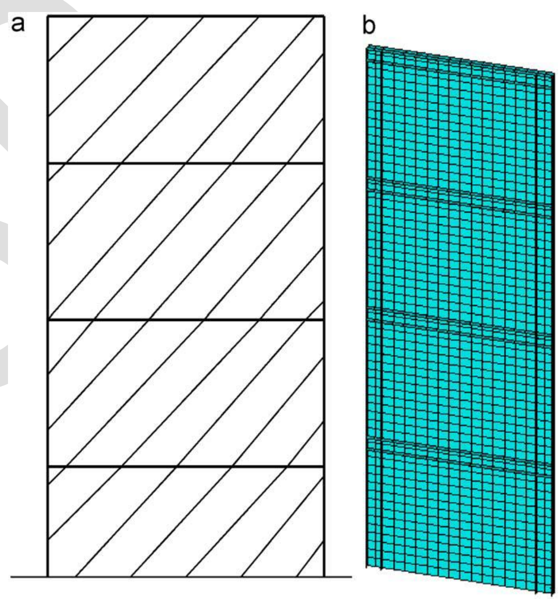
Fig 2.1 Load-drift curve RC moment and braced RC moment frame

Design specifications provide empirical formula to estimate fundamental natural period of system. In this study a class of steel plate shears walls that has uniform properties through their height was considered. The fundamental time period of these class of structures were determined using three dimensional geometrically linear finite element analysis and compared with estimation provided by seismic design specifications. Comparison reveals that estimations using approximate formula can lead to unsatisfactory results. Based on these observations a simple hand method has been developed to predict the fundamental period of shear walls.[5]

In order to study the cyclic response of tubular bracing members of three structural materials hot rolled carbon steel, cold-formed carbon steel and cold-formed stainless steel, a total of 16 square and rectangular hollow section members were tested under cyclic axial loading. The load displacement hysteretic response, compressive resistance, lateral deflection, energy dissipation and fracture life of the specimens of these three materials were investigated. In addition, finite element models, verified against the experimental results from the current study and two other research programmes, were used in conjunction with a strain-based damage prediction method to conduct parametric studies. It is shown that existing empirical expressions for predicting the buckling resistance, post-buckling compressive strength and mid-length lateral deflections can be applied to both carbon steel and stainless steel specimens. However, the relationships between member ductility and slenderness are not representative over the full slenderness range, and are not applicable to cold-formed stainless steel members. New relationships, one for each material, are proposed to take into account the inter-relationship between global slenderness and local slenderness. The tangent stiffness throughout the loading cycle, which differed between the three materials, is found to be a crucial factor in determining the resistance to local buckling and number of cycles to failure of the braces.[6]

The accuracy finite element method and strip method of analysis for calculating the lateral stiffness of steel plate shear wall (SPSW) system is assessed by making comparison with experimental findings. Comparisons revealed that while both methods provide acceptable accuracy, they also require the generation of sophisticated computer models. In this paper, two alternative methods are developed. The first one is an approximate hand method based on the deep beam theory. The classical deep beam theory is modified in the light of parametric studies performed on restrained thin plates under pure shear and pure bending. The second one is a computer method based on the truss analogy. Stiffness predictions using the two alternative methods are found to compare well with the experimental findings. Comparison shows that the both methods show acceptable accuracy. FE over predicts the stiffness (23%) while strip method analysis provides under predictions (21%).[7]

This paper introduces steel plate shear walls as a primary lateral force resisting systems. Authors designed The Jinta Tower (75 story) building located in Tianjin,



B fig 2.2 Strip and FE methods

China with slender steel plate shear wall (SPSW) used as a primary lateral load resisting system. Chinese codes require that steel plates not buckle in frequent (50 year) seismic events in addition to typical performance requirements I the moderate (475 year) and rare (2000 year). To address these constrains, a buckling restrained slender steel plate shear wall system, with vertical stiffeners to enhance gravity load carrying capacity of the plate and delay buckling is developed.

It is observed that SPSW's stiffness is much higher than concrete shear walls for same tonnage of steel and very significant ductility under moderate and rare earthquake resulting from tension field action. Compared to reinforced concrete, in steel plate shear walls resulting in less weight to be carried by foundations as well as lower seismic loads due to the reduced seismic mass.[8]

Braced tubes are efficient structural systems for tall buildings and have been continuously used for major tall buildings since their emergence in the late 1960s. This paper presents a stiffness-based design methodology for determining preliminary member sizes of braced tubes for tall buildings. The methodology is applied to a set of buildings ranging from 40 to 80 stories tall, and parameters for the most economic design in terms of material usage are generated for representative design loadings. The impact of different geometric configurations of the structural members on the economic design is also discussed, and recommendations for the optimal geometries are made. The stiffness-based methodology, with a less iterative process, is very efficient for the preliminary design of braced tube structures, and will contribute to constructing built environments using minimum amounts of resources.

Lateral load carrying capacity of the braced frame within a building's interior core is much smaller than that of the later-developed exterior braced tube on a building's perimeter. The lateral stiffness of perimeter braced tubes can be enhanced by adding lateral load resisting core structures, such as steel braced cores or concrete shear cores. Studies show that typical braced cores contribute about 20% of the total lateral rigidity in properly designed braced tube tall buildings.[9]

Tall buildings are built with an abundant amount of resources because of their enormous scale. This paper presents sustainable structural engineering strategies for tall buildings, which will lead to the construction of tall buildings with less amount of structural material to meet design requirements. Selecting a particular structural system for tall building design involves many complex factors such as availability of resources, architectural aesthetics, spatial organizations and structural efficiency. Among these various factors, this study mainly investigates lateral stiffness-based structural efficiency of today's prevalent structural systems for tall buildings, such as diagrids, braced tubes and outrigger systems. Design optimization strategies for important structural geometric configurations are studied. Further, optimal stiffness distribution between the building core and perimeter structure is discussed. Through the most appropriate system selection and design optimization, more sustainable built environments can be accomplished.

Among various tubular structures, the braced tube system with diagonals is generally more efficient than other tube systems composed of only orthogonal members because the tube members in the braced tube system carry lateral loads by their axial actions.[10]

This paper reports some aspects of this devastating earthquake which hit an advanced country in seismic resistant design. It has been reported that long-period ground motions were induced in Tokyo, Nagoya and Osaka. The properties of these long-period ground motions are discussed from the viewpoint of critical excitation and the seismic behavior of two steel buildings of 40 and 60 stories subjected to the long-period ground motion recorded at Shinjuku, Tokyo is determined and discussed. This paper also reports the effectiveness of visco-elastic dampers like high-hardness rubber dampers in the reduction of responses of super high-rise buildings subjected to such long-period ground motions. The response reduction rate is investigated in detail in addition to the maximum response reduction. In December 2010 before this earthquake, simulated long-period ground motions for earthquake resistant design of high-rise buildings were provided in three large cities in Japan (Tokyo, Nagoya and Osaka) and nine areas were classified. Two 40-story steel buildings (slightly flexible and stiff) are subjected to these long-period ground motions in those nine areas for the detailed investigation of response character- istics of super high-rise buildings in various areas.[11]

III. STEEL PLATE SHEAR WALLS AND BRACINGS

A. *Background of SPSWs*

The main function of steel plate shear wall is to resist horizontal story shear and overturning moment due to lateral loads. Steel plate shear walls (SPSW) can be used as a lateral load resisting system for buildings. A typical SPSW (Fig.) consists of stiff horizontal and vertical boundary elements (HBE and VBE) and infill plates. The resulting system is a stiff cantilever wall which resembles a vertical plate girder

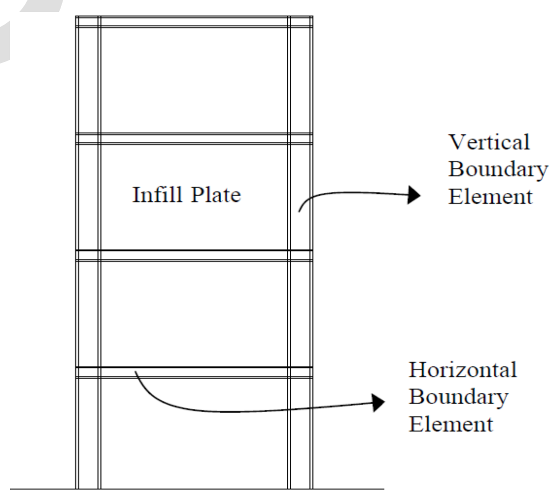
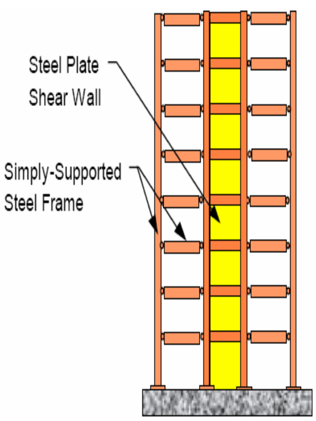


fig. 3.1 Typical Steel Plate Shear Wall

There are two types of SPSW systems, which are the standard system and the dual system. In the standard system SPSW is used as the sole lateral load resisting system and pin type beam to column connections are used in the rest of the steel framing. In the latter system, SPSW is a part of a lateral load resisting system and installed in a moment resisting frame. In this case forces are resisted by the frame and SPSW. SPSW can have stiffened or unstiffened infill plates depending on the design philosophy.

Earlier designs used stiffeners to prevent buckling of infill plates under shear stresses. On the other hand, more recent approaches rely on post buckling strength. Based on the work of Wagner, it has been known that buckling does not necessarily represent the limit of structural usefulness and there is considerable post buckling strength possessed by restrained unstiffened thin plates. At the onset of buckling, this occurs at very low lateral loads, the load carrying mechanism changes from in-plane shear to an inclined tension field. The additional post buckling strength due to the formation of tension field can be utilized to resist lateral forces. Due to the cost associated with stiffeners most new designs employ unstiffened infill plates.

Design recommendations for SPSW systems are newly introduced into the AISC Seismic Provisions for Structural Steel Building. These provisions basically present guidelines on the calculation of lateral load capacity of SPSW as well as recommendations on the seismic characteristics. Lateral load resisting capacity of SPSW systems has been studied experimentally and numerically in the past and procedures for computing the nominal capacity are developed. These experimental and analytical studies led to the development of code provisions.[12]



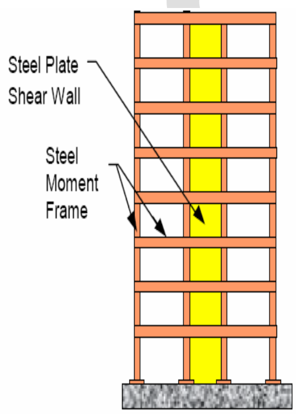


fig. 3.2 Standard SPSW system

fig. 3.3 Dual SPSW system

IV. MODELING AND ANALYSIS

A. General:

The main objective of applying lateral force resisting systems to tall building is to increase the stiffness when building is subjected to lateral loads and restrict performance criteria's to the specified limit by IS Codes. For this purpose Response spectra and linear time history analysis is used to evaluate performance of the building. The modelling and analysis is done through ETAB 14 software.

1) Description of Structure:

The building considered for analysis is a G+75 story tube in tube structure composite building designed using Indian codes IS 456-2000 and 875 (I & II)-2002. The plan area of building is 40 x 60m with 4.2m height of each typical story (excluding bottom and top story which are 6m height). It consists of 8 bays of 5 m. each in X-direction and 12 bays of 5 m. each in Y-direction. Material properties are assumed to be 25 and 60MPa for the concrete compressive strength. The labels of beam and column along with the frame dimensions are shown in Table

B. Performance Criteria:

For a normal building there are mainly two performance criteria's maximum displacement and drift. But in case of high rise buildings due slenderness of building acceleration is also important performance criteria. If acceleration goes above comfort level, building will be unserviceable. The maximum target displacement of the structure is calculated in accordance with the guidelines given by IS Code for maximum roof level lateral displacement and drift.

The building is designed by according to I.S. 456:2000 for Dead Load and Live load.

1) Displacement: According to IS 456 lateral deflection at the top of building should not greater than H/500. Where, H is total height of structure.[13]

2) Drift: According to IS 1893 the story drift in any story due to minimum specified design lateral force shall not exceed 0.004 times story height

3) Acceleration: Any Indian code does not give detailed criteria about maximum acceleration level in building. According to research papers human beings can sense acceleration above 0.1 m/s2 and 0.1 to 0.2 is perceptible.

V. CONCLUSION:

1. SPSW and bracing as a lateral force resisting systems can gives superior performance against displacement and drift as compared to uncontrolled state.
2. Comparison of Bracing system, and SPSW systems
3. Bracing system gives superior performance against acceleration as compared to SPSW.

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