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Seismic Performance of A Regular Steel Building with A Controlled Cradle System

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Abstract

During a large earthquake, traditional lateral seismic resistance systems can suffer serious damage to the structural system, and many buildings need to quickly return to their original function and function after an earthquake. One of the suggested methods is to use the rocking motion of the building at the base. In fact, it can be said that the basis of this plan is based on the idea that the building should be designed and implemented in such a way that it is not completely attached to the ground and moves like a cradle during an earthquake; in this case, the structure is expected to withstand the incoming movements and earthquake damage is generally concentrated in predetermined and easily repairable points in the structure. The lateral load-bearing system of divergent bracing absorbs horizontal deformations due to the presence of the connecting member, thereby providing a high energy absorption capability for the structure. It is also possible to replace the connecting member after an earthquake occurs. In this study, after verifying and ensuring the modeling method, 3-, 6-, 9-, and 12-story models with a link member system in different base vector states were examined. The results indicate that the method of fixing the base of the structure has a great impact.

Keywords: Rocking motion, Divergent brace, Connecting member, Energy absorption.

1 | Introduction

Tony et al. [1] in 2003 proposed ideas about a generation of systems that cause damage to a specific part of the structure. In this time frame, researchers conducted experiments on a type of prestressed shear wall. Palermo et al. [2] in 2004 reached conclusions on the use of rocking motion in bridges. In this study, software analysis based on the theory of finite element methods and the classical matrix method of numerical nonlinear static and dynamic analysis was performed on bridge foundations that allowed cradle motion. Azuhata et al. [3] invented systems with reversible properties associated with cradle motion in 2008. These systems can prevent structural failure due to permanent deformation and relative displacement during successive earthquakes by using the self-weight of the structure as a reversible property.

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Tremblay et al. [4] in 2008, subjected horizontal metal load-bearing system frames with viscous dampers that have a rocking motion to software analysis based on the theory of finite element methods and the classical matrix method and interpretation through parametric studies and comparison with laboratory results.

And as a result, according to the schematic, it was found that the use of such systems improves the seismic performance of the structure. In 2006, Ayestarán and Graciano [5] subjected a metal horizontal load-bearing system with controlled cradle motion and energy-absorbing fuses to software analysis based on the theory of finite element methods and the classical matrix method and interpretation.

In 2015, Plinio [6] conducted a software analysis based on the theory of finite element methods and the classical matrix method, and interpreted and simplified the transfer of applied load in the form of force in the frames of a horizontal metal load-bearing system with cradle motion and energy-dissipating parts in order to determine the response of the applied load in the form of force and maximum displacement and evaluate the response of these systems.

Restrepo and Rahman et al. [7] conducted research in 2007 on the seismic performance of centripetal concrete wall structural systems with energy dissipators. In fact, many seismic codes allow a certain reduction in design loads. Considering this point, structures with significant reserve resistance (additive resistance) and high capacity for energy absorption (ductility) are considered, which is incorporated in the design of structures by considering the behavior coefficient.

Due to the special sensitivity that exists in the design and implementation of concrete structures, as well as the impact of the cross-sectional dimensions of members on the amount and load-bearing capacity of the member and ultimately the entire system, the application of the effects of Soil-Structure Interaction (SSI) in the analysis and design of concrete structures and the change in the internal force of members resulting from this phenomenon will be effective both in terms of the safety of the design and its economy [8].

On the other hand, since the seismic design of concrete structures, determining the structural behavior coefficient and ensuring the ductility of its members is done based on the performance level of the members (performance-based design), therefore, the identification of the structural behavior and its seismic response and reflection is largely dependent on the modeling of the subsoil of the structure. This issue was stated in 2011 by Shakib and Atefatdoost and also by ESER et al. in 2011 [8].

The effects of SSI and the importance of the changes in the seismic response of a structure caused by the analysis of this set of behaviors are generally unacceptable. These effects may increase or decrease the seismic response of the structure or its other seismic parameters under the influence of the earthquake force, which themselves depend on the characteristics of the free field motion, the dynamic properties of the structure (including the fundamental vibration period, damping, etc.), and the flexibility of the support. similarly, it is possible that as these changes occur, the force in structural members may also change (decrease or increase), affecting their safety, efficiency, or durability [10].

2 | Types of Lateral Load-Resistant Systems

In this section, we will provide a general introduction to common systems that resist lateral loads. The only mention of resistant systems will be limited to the following. Because the purpose is not to explain how and how resistant systems work. Rather, the purpose is the effect and role of the tensile strength of steel in their function. In general, to cope with the load applied in the form of lateral force caused by an earthquake, various systems can be used, such as

I. Reinforced concrete shear walls.

II. Metal shear walls.

III. Horizontal load-bearing system.

IV. Concrete and metal flexural forms.

Of course, combining the aforementioned systems is also a suitable option.

For example, the Nippon Steel structure in Tokyo uses a combination of metal bending formwork and metal shear walls, the Shinjunokumura structure in Tokyo uses a metal shear wall system, the Hyatt Regency structure in Dallas, USA uses a metal shear wall, and the Oliveview Hospital in California, USA uses shear walls with a hinge.

2.1 | Concrete Shear Wall System

The load applied in the form of a lateral force acting on the structure (due to wind or earthquake) is dealt with in various ways. The elements resisting the applied load in the form of the above forces include a bending frame, a shear wall, or a combination of them. Using a flexural frame as a resisting element against loads applied in the form of lateral forces, especially if the loads applied in the form of lateral forces are due to earthquakes, It requires compliance with specific details that ensure sufficient formability of the form. These details are often cumbersome in terms of execution, and if their precise execution is ensured, the quality of execution and supervision in the workshop will be very high.

One of the safest methods for dealing with loads in the form of lateral forces is to use a reinforced concrete shear wall. Shear walls can be placed in various parts of a structure plan, depending on architectural considerations, but care must be taken to ensure that their placement in the plan is as symmetrical as possible. Walls are generally subjected to the following forces:

I. The applied load is in the form of a shear force, the value of which is essentially maximum.

II. Variable bending anchor, whose value is maximum at the foot of the wall and creates tension at one edge and pressure at the opposite edge.

III. The applied load is in the form of a compressive axial force resulting from the weight of the floors resting on the shear wall.

If the height of the shear wall is low, the applied load will often be in the form of shear force, but if the height of the shear wall is high, the bending moment will dominate the design. The shear wall is designed like a reinforced concrete beam.

2.2 | Types of Molds

I. Gabled, which has one vertex.

II. Portal: similar to a door. Multi-span, multi-story portal frames are commonly used for commercial and industrial structures. The floor behavior is similar to that of a full-length beam.

III. Alternating truss: the trusses of the floors are built in alternating patterns at the openings of the formwork to create wider floors.

2.3 | Connections

I. Metal: the top of the members is completely connected to the top of the other members. This can be done by welding or bolted plates.

II. Concrete: connections are made integrally with continuous flexural reinforcement. Shear is controlled using stirrups and necessary restraints.

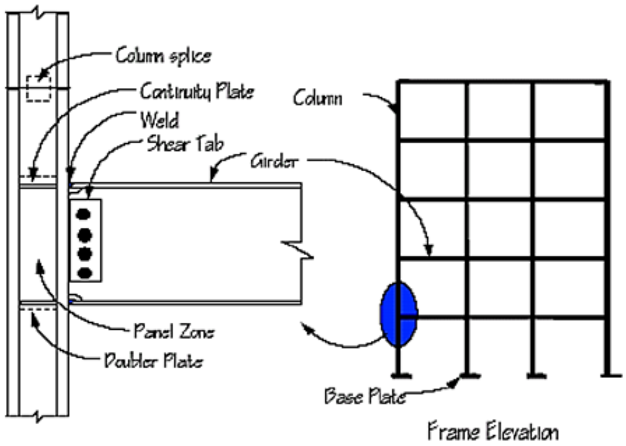

Fig. 1. An example of a bending mold and its connections.

2.4 | Types of Shear Walls

The load applied in the form of lateral forces acting on a structure (due to wind or earthquake) is dealt with in various ways, making the effect of an earthquake on structures completely different from other effects on them. The characteristic of the effect of an earthquake is that the load applied in the form of forces resulting from it is much more intense and complex than other loads applied in the form of effective forces. Resisting elements against the applied load in the form of superimposed forces include a bending frame, a shear wall, or a combination of the two.

Using a flexural formwork as a resisting element against loads applied in the form of lateral forces, especially if the loads applied in the form of lateral forces are due to earthquakes, requires special details that provide sufficient ductility of the formwork. These details are often cumbersome in terms of execution, and their precise execution can only be ensured if the quality of execution and supervision in the workshop is very high. In terms of superiority, it can be said that the shear wall is more economical than the formwork and controls the change of locations, while for tall structures, the formwork alone cannot be responsible in this regard.

Metal shear wall: It is used to strengthen metal structures and, with its connections, strengthens the surrounding beams and columns; and has advantages such as easy implementation, low weight, economy, high ductility, quick installation, and high energy absorption.

Composite shear wall:

I. Reinforced metal sheets embedded in reinforced concrete.

II. Metal sheet trusses embedded inside reinforced concrete wall.

Masonry shear wall: reinforced shear walls such as walls with hollow bricks and mortar filled.

Reinforced concrete shear wall:

I. In-situ.

II. Prefabricated.

One of the most reliable methods of resisting the applied load is in the form of lateral forces. Its placement in the plan should be as symmetrical as possible. The center of gravity of each floor should be around the center of rigidity of the shear walls.

There are two types of reinforced concrete shear walls:

I. Shear wall in place: in an in-place shear wall, the wall rebar is hooked into the surrounding formwork to maintain uniformity and continuity.

II. Prefabricated shear wall: in prefabricated shear walls, uniformity and continuity are achieved by providing trapezoidal joints along the edges of the panel or by connecting the panels to the formwork with metal nails.

III. Effect of wall shape: installing the ball in the walls is very useful for the stability and ductility of the structure.

The applied load in the form of forces acting on the shear walls.

In general, shear walls are subjected to loads in the form of the following forces:

I. The applied load is in the form of a variable shear force, the value of which is essentially maximum.

II. Variable bending moment, whose value is again maximum at the foot of the wall and creates tension at one edge (The edge closest to the applied load responds to forces and pressure at the edge). Considering the possibility of changing the direction of the applied load in the form of wind or earthquake forces in the building, tension must be considered at both edges of the wall.

III. The applied load is in the form of a compressive axial force resulting from the weight of the floors resting on the shear wall.

If the height of the shear wall is low, the applied load will mostly be in the form of shear force, but if the height of the shear wall is high, the bending moment will dominate the design. However, the wall must be reinforced against each applied load in the form of an over-control force.

2.4.1 | Materials used in concrete shear walls

I. Reinforcement.

II. Concrete.

III. Formwork.

After the foundation is constructed and the columns are concreting, it is time to construct the shear wall.

2.4.2 | Advantages of shear walls

I. Significantly increasing the stiffness of the structure in a way that has an effective role in secondary effects. This advantage automatically increases the degree of safety against failure or collapse of the structure.

II. Significant reduction in damage to non-structural elements, the cost of which in most cases is not less than the cost of structural members.

III. A significant effect in creating peace of mind and ensuring psychological security for residents of high-rise structures during an earthquake.

IV. Shear walls are able to withstand the gravity loads for which they are designed, even after receiving many cracks. This phenomenon cannot be fully expected from columns.

V. High formability

2.4.3 | Disadvantages of shear walls

Possibility of shear failure if not properly designed:

Creation of an applied load in the form of a vertical force if the number of walls is not correctly estimated and their improper placement

What should be considered for shear walls are: Strength, ductility, energy absorption capacity, minimum reduction in hardness.

Any shear wall may undergo displacement or translational and rotational deformation due to applied loads in the form of axial forces.

The extent to which and how a shear wall is affected by overturning moment, applied load in the form of shear or torsional forces, depends on: Geometric shape, its direction against the applied load in the form of earthquake force, its location in the building plan.

Wing: walls that have wings at both ends are called winged sections, which have greater stability and ductility compared to walls without wings.

2.5 | Types of Shear Walls in Terms of Shape, Geometry of The Cross-Section of The Element

I. Rectangular shear wall with uniform reinforcement throughout the geometry of the cross-section of the element.

II. Rectangular shear wall with concentrated reinforcement at both ends of the wall.

III. Dumbbell-shaped or I-shaped shear wall.

In shear walls with abutments, if the wall has one or more buttresses at its lowest part, each of the wall components on either side of the buttress is called the foundation of the shear wall, and the part of the wall between the upper and lower buttress is called the tie beam or compartment.

To create a single structural function for two adjacent and separate structural walls or for the components on both sides of the opening in walls with large openings, highly ductile connecting beams called tie beams are used. In this case, the walls that are connected are called tied walls. In any case, the width of the tie beam is at least 200mm.

2.5.1 | Points related to bending molds

Flexural frames are very sensitive to the arrangement of live loads and their effect on the values of flexural moments.

Columns of a flexural frame will be stronger than simple frames because the lateral stiffness of flexural frames is more affected by the column. Beams located in flexural frames are generally lighter than simple frames because a balanced distribution of bending moment is achieved due to the rigid connection. In flexural structures, due to the large number of rigid connections, this type of frame requires more expertise and time in terms of cost.

2.5.2 | Advantages of bending molds

I. The possibility of maneuvering and flexibility in architecture and renovations.

II. Appropriate ductility and the possibility of absorbing earthquake energy.

III. Adjustment of tensile-compressive forces acting on the column base.

2.5.3 | Disadvantages of bending molds

I. Complex and heavy connections in terms of execution.

II. Large lateral displacement and increased stiffness of beams and columns to reduce this defect.

III. Implementation of a clamped connection at the column base and transfer of heavy anchorage to the foundation.

IV. Significant increase in the weight of the foundation compared to a simple formwork.

3 | Definition of Software Analysis Based on The Theory of Finite Element Methods and The Classical Nonlinear Static Matrix Method (Pushover)

Pushover analysis is a software analysis based on the theory of finite element methods and the classical nonlinear static matrix method under the influence of increasing lateral loads. The purpose of the software analysis based on the theory of finite element methods and the classical nonlinear static matrix method is toestimate the expected behavior of a structural system by estimating the required resistance and deformation ,By performing a software analysis based on the theory of finite element methods and the classical nonlinear static matrix method, taking into account design earthquakes, and then comparing the required values with the existing capacities at the behavioral or functional level, it is considered.

This estimate will be based on the identification of important behavioral parameters, including lateral displacement, relative shape changes of members and connections, etc. Analytical methods that are proposed in the performance-based design and seismic design of structures , They are mainly based on nonlinear static analysis. The reason for the preference for using this type of analysis is its high speed of execution, The simplicity of interpretation of the results and their accuracy are acceptable. However, complex analyses are not economically justifiable except in very special cases or when sufficient information is available to demonstrate the correct cyclic loading behavior, changing the shape of structural members.

4 | Conclusions

Cradle motion in the studied frames, according to the results of the average of 7 earthquake accelerometers obtained from fixed accelerometers based on the Peer database of the University of Berkeley, mapped at two scales of software analysis based on the theory of finite element methods and the classical and interpreted matrix method in this research ,This has resulted in improved foundation shear and axial stress conditions of the first-story columns compared to the formwork with fixed foundations. In this method, by dissipating part of the applied load in the form of dynamic force acting on the structure, instead of increasing the ductility of individual structural elements and increasing the weight of the building excessively, elements with smaller cross-sections can be used in the design of the structure. A lighter structure can be designed.

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Author Contributions

Conceptualization, B.J. and M.E.; Methodology, B.J.; Software, B.J.; Validation, B.J. and M.E.; Formal analysis, B.J.; Investigation, B.J.; Resources, M.E.; Data curation, B.J.; Writing original draft preparation, B.J.; Writing review and editing, M.E.; Visualization, B.J.; Supervision, M.E.; Project administration, B.J. and M.E. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Numerical analysis data and simulation outputs generated during the study are not publicly available due to research limitations and project confidentiality.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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