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# Seismic Behavior of Reinforced Concrete Slit Shear Walls Energy Dissipators

Shinde R. M.[1], Deshpande P. K.[2], Wankhade R. L.[3]
[1](PG Student M.E. (Structures), Government College of Engineering, Karad. India)
[2](Assistant Professor, Applied Mechanics Department, Government College of Engineering, Karad. India)
[3](Assistant Professor, Applied Mechanics Department, Government College of Engineering, Karad. India)

***ABSTRACT:*** *The types of slit walls energy dissipators, from monolith or precast reinforced concrete, proposed by researchers and the seismic behavior of these types of walls are described. The overall ductility of the structure increases, considering the energy dissipation solutions proposed by the researchers of the reinforced concrete walls, resulting a supplementary safety for the structure. The objective of these solutions is to create an ideal structure for tall multi-storey buildings, that behaves as a rigid structure at low seismic action and turns into a flexible one in case of a high intensity earthquake action. The solutions for increasing ductility proposed in this paper are viable and easily to use in constructions practice. For the analysis of slit wall, the researchers used a series of analytical calculation methods, among the most important being the equivalent frame method and the finite element method. The researchers concluded that by using these calculation methods, the dynamic behavior of the reinforced concrete slit walls can be simulated very accurate and realistic.*
***Keywords:*** *ductility, energy dissipator walls, equivalent frame method, finite element method, lateral resistance.*

## 1. INTRODUCTION

Reinforced concrete walls are strength and portant elements frequently used in constructions in seismic areas, because they have a high lateral stiffness and resistance to external horizontal loads. If the wall stiffness is high, the seismic loads taken by the structure become higher, resulting non-economic sections for the wall. This phenomenon occurs particularly in multi-storey tall buildings. In case of high intensity earthquakes flexible structures are preferred because can accept large deformations, instead for low intensity earthquakes that occur frequently, or for wind action, rigid structures should be considered, because prevent large displacements. The dissipation of the accumulated energy in the structural wall systems occurs generally through concentrated degradation at the base of the wall (Fig. 1), which is difficult to repair. For the wall showed in Fig. 1 two negative characteristics are pointed: low ductility and low redundancy.

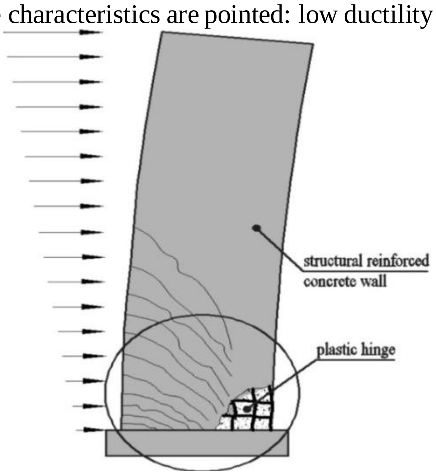


Fig. 1 – destruction of reinforced concrete walls at horizontal seismic action.

Numerous investigations have been made to improve redundancy and ductility of structural walls exposed at horizontal actions and some practical solutions were proposed. Slit walls are a special variant of structural walls with improved ductility. The specialists intention was to reduce the degradation from the base of the wall and distribute it on the wall height. The plastic hinge formation furnishes gives to the structure kinetic energy dissipation capacity, but also constitutes a state of structural damage. A performance based design will ensure the life safety and viable rehabilitation from economical point of view to a building subjected to major earthquake.

1.1 Slit Walls Evolution

A particular reinforced concrete structural wall, with good properties of seismic energy dissipation, called slit wall, was patented by Professor K. Muto in Japan, in 1973. These walls are the first energy dissipation system used in the structures of Japan. The first building made with this system is the Keio Plaza from Tokyo (1968), a 36-storey frame structure made of steel. In the structure frameworks, vertical strips of concrete forming a slit panel are introduced. The contact between the strips is made with plaster, asbestos sheets, synthetic resin or metal plates (Fig. 2). Seismic energy dissipation is achieved by destroying the connection between the reinforced concrete strips. The goal of this invention is to create an ideal structure for high multistory buildings, which under reduced seismic actions behaves as a rigid structure and under the action of high intensity earthquakes turns into a flexible one. Initial energy dissipation was achieved by the cracks distribution on a large surface in slit panels.

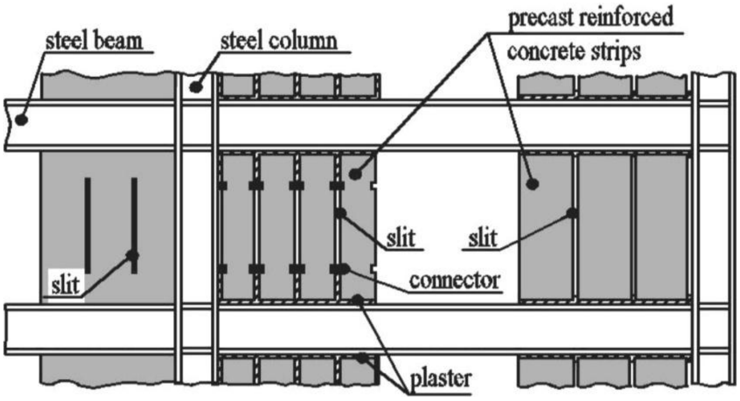


Fig.2 – slitted panels

Korean researchers have proposed another type of slit wall used especially for reinforced concrete structures, in which strips are anchored in beams. Compared with slit walls made of prefabricated strips, these walls have a better ductility, a higher energy dissipation capacity and accept greater lateral displacements. The structural behavior of these panels is influenced by the concrete properties of the strips, the panel size, the axial loading intensity, the slit thickness and the material added in slit.

In order to increase the amount of energy dissipated by a reinforced concrete wall, researchers at the University of Tehran have examined other slit wall. They introduced a large number of slits at the top of the structural wall and a reduced number of slits at the base. In this case failure results from the action of shear force on each strip. If the number of slits increases the structural wall behaves more ductile and the number of plastic hinges is higher, resulting an increase of the energy dissipated by the wall height.

A slit wall model was proposed at the University of Shanghai, China, by X. Lu and X. Wu in 1996. They have inserted between the reinforced concrete strips rubber belts dissipative of kinetic energy. To improve the seismic behavior, at each level of the structure connections with four reinforcement bars which pierce the rubber belt and which are anchored into the wall are made. The system thus formed has a very good ability to dissipate the seismic energy. Seismic energy is dissipated by the elastic rubber deformation, the yielding of the reinforcements from the connections and the friction between concrete and rubber strap. Considering this structural solution were built two buildings with 38 floors in Shanghai in 1997.

## 2. ANALYTICAL METHODS FOR SLIT WALL DESIGN

For the analysis of slit wall, the researchers used a series of computation methods, among the most important being the equivalent frame method and the finite element method.

2.1 Equivalent frame method

The equivalent frame method is used to design slit walls with reinforced concrete short connections. Structural walls are modeled as columns and connections are modeled as flexible beams in slit region and as infinite rigid beams in the wall region. For analysis of the structural system a standard frame program is used. In the analysis the nonlinear inelastic behavior of the connections is accepted while for the columns the linear elastic behavior is taken into account, because it is considered that the walls are not degraded by the seismic action. Equivalent frame method used to design reinforced concrete slit walls with connections has the advantages that is simple, easily to understand and allows a faster analysis compared with the finite element method.

Step integration Newark β method is commonly used by researchers for nonlinear dynamic analysis to obtain the dynamic equation of motion solutions. To obtain an accurately dynamic response of the structure, the time step must be below 1 ms. The dynamic equation of motion at any time *t*, is written incrementally in the following form:

: $M\Delta\ddot{u} + C\Delta\dot{u} + K\Delta u = \Delta p(t)$………(1)

Where,

M is mass matrix of the structure

C = αM +βK – damping matrix of the structure

α, β – specific parameters Newark β integration method

K – stiffness matrix of the structure

$\Delta\ddot{u}, \Delta\dot{u}, \Delta u$ – vectors of incremental nodal acceleration, velocity and displacement respectively

$\Delta p(t)$ – incremental vector of applied load.

2.2 Finite element method

The principal of finite element method (FEM) analysis consists in decomposition of the domain in parts of simple geometric shape, analysis and field recomposition that respect certain physical and mechanical requirements. To simulate the seismic behavior of the reinforced concrete walls, the researchers are using several finite element programs such as Ansys, Etabs, Robot Millenium etc.

For modeling concrete in Ansys Solid 65 element is used which is having 8 nodes (Fig. 3). Researchers showed that concrete simulations with this element are very accurate. The curve shown in fig. 3 corresponds to compression and stretching of the concrete. The stress-strain compression curve for concrete is linear-elastic up to 30% of the maximum compression pressure. After this value, it reaches the maximum compression pressure $\sigma_{cu}$ , the curve decreases, failure occurring to the last deflection, $\varepsilon_{cu.}$ In stretching, the stress-strain curve for concrete is approximately linear-elastic up to the maximum tensile stress, $\sigma_{cu}$. After this point, the concrete cracks and the tension decreases up to zero.

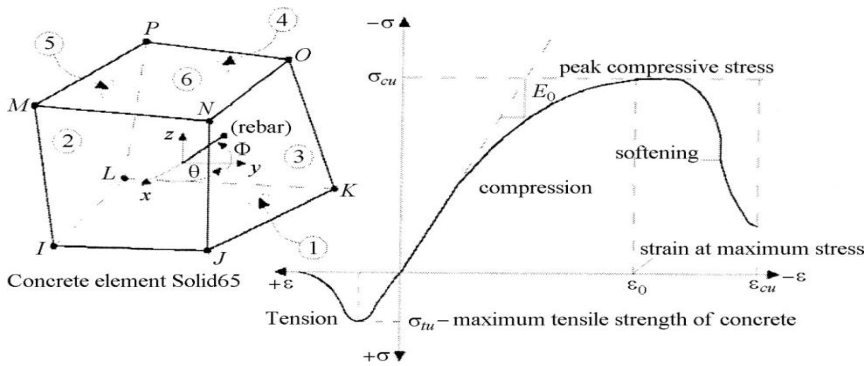


**Fig. 3: finite element Solid65 and concrete compressive and tensile curve.**

In Ansys, steel reinforcement bars are used to reinforce the wall structure are modeled with individual finite element bar type, being used Link 8 element (fig. 4). Reinforcement distribution in concrete structure is used for simplification, entering the reinforcement percentage and the steel properties on each direction. Link 8 element has two nodes and each node has three degrees of freedom. Steel finite elements Link 8 have identical behavior in compression and in tension (fig. 4). The material is considered elastic-perfectly plastic.

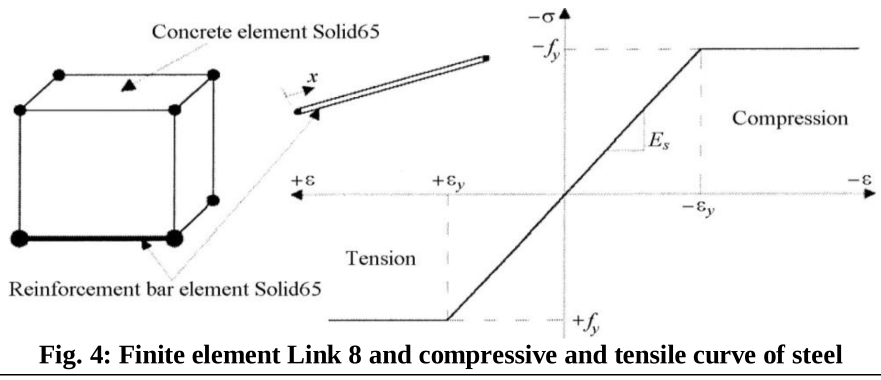


**Fig. 4: Finite element Link 8 and compressive and tensile curve of steel**

## 3. CONCLUSION

An economical design of buildings based on performance takes into account the dissipation of seismic energy accumulated in the structure. Reinforced concrete walls are frequently used as strength elements for structures designed in areas with high seismic risk. The main problems of these structural elements are low ductility and redundancy which can be removed by using reinforced concrete slit shear walls. Research has shown remarkable improvement of the structural slit walls, very good seismic behavior, stable hysteretic curves with high kinetic energy dissipation. With this solution the degradation in the shear wall are greatly reduced, potential plastic zone is positioned along the height of the wall and energy dissipation is achieved by the crushing of the reinforced concrete shear connections. The plastic hinge formation furnishes to the structure kinetic energy dissipation capacity, but also constitutes a state of structural damage. A performance-based design will ensure the life safety and viable rehabilitation from economical point of view to a building subjected to a major earthquake.

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