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Comparison of Seismic Behavior of Linear and L-shaped Section Reinforced Concrete Shear Walls

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Abstract: This paper aims at comparing the seismic behavior of straight linear shear wall and L-shaped shear wall. In order to investigate the seismic behavior, hysteretic diagrams of both types of wall under cyclic loading have been drawn since the hysteretic diagrams are the best reflexive diagrams of the seismic behavior of the structural parts under the seismic loading. The research methodology includes modeling or simulating seismic behavior of the concrete walls that have been modeled by ABAQUS (FEM). To make sure of the accuracy of the modeling process and its parameters, data verification has been performed by comparison of the results of limited laboratory elements' analysis. The results of this study indicate that after modeling, analyzing, and drawing the hysteretic diagrams in the considered wall model, the straight linear wall behavior shows more ductility than the L-shaped wall. It is due to that fact that creating concentrated torsional tensions on the corner of L-shaped wall can decrease the concrete's ductility and strength in this region and have a more brittle behavior than the straight linear walls.

Key words: *Reinforced concrete shear walls; Linear section; L-shaped section; Seismic behavior; FEM method*

1. Introduction

The previous experiences show that in the regions in which the designing and estimating the building rules and regulation against the earthquake have been applied, the casualties and damages have been negligible, while those regions did not consider these rules and regulations have experienced more damage and casualties in medium earthquakes such as Bam earthquake (2003). The issue indicates the importance and effect of engineering knowledge to prevent or decrease the damaging effect of earthquake and natural disasters (Mahdavi et al., 2011 & 2012).

Shear wall is a wall that has been consisted of anchor elements (shear elements). This wall has been designed to be resistant against the permanent axial effect, bending attempt, and shear attempt resulted from the vertical loads and the lateral loads of the earthquake and is responsible for neutralizing the mentioned loads on the structure. Shear wall usually bears the most shear force of the abutment which causes the remarkable increasing of the building stiffness and decreasing the damage to the non-structural elements remarkably. So, shear wall is a type of structural system that provides the lateral strength of the building or the structure. The lateral forces in a plate are imposed along the vertical joint of the wall. These types of loads are usually transferred to the wall by the diaphragm or collective parts. These walls are made of wood, masonry materials, or concrete. Depending on the conditions of a design instead of a flat rectangular or linear wall a non-flat shear wall like L-shaped shear wall can be used. Applying these types of shear walls requires three-dimensional analysis and investigating the region's conditions which are among the common methods of the confined elements. Also, the resistant elements against the lateral forces include the bending frame, shear wall, or a combined of the both. Shear wall is more economic than bending frame and the frame cannot be responsive for the tall structures and increases the building stiffness (Nategh Elahi, 2004).

Six types of reinforced concrete have been tested in this article among which a sample (WSH6) has been selected and tested about cyclic loading. Applying the mentioned wall (WSH6) in the ABAQUS software it was modeled according to finite-element method and the obtained results were investigated and compared with the laboratory results (Chenug et. Al., 1991).

In fact, shear walls location in the appropriate places of the structure's plan and providing the appropriate details for them can result in a structure with stiffness, resistance, and also appropriate ductility. This is an appropriate choice as the lateral bearing system in the seismic regions. Regarding this issue, implementing non-linear analyses to investigate the walls' behavior realistically is inevitable.

Shear walls modeling should be done such that the walls can consider the dislocation effects of the neutral fiber because of the loadings changes,

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concrete hardening, progressive opening and closing of the concrete, non-linear shear behavior, shear and bending interaction appropriately. Types of shear walls based on the materials are steel shear wall, combined shear wall, masonry material shear wall and reinforced concrete shear wall that will be briefly discussed (Moghadam. 2005).

1) Steel is used for making the steel buildings strength and enhances the lateral beams and columns. It has some advantages as easy implementation, low weight, being economic, high ductility, quick installation, and high energy absorption.
2) Combined shear wall includes the reinforced steel sheets laid in the reinforced concrete, steel trusses laid in the reinforced concrete shear wall.
3) Masonry material shear walls are the shear walls made of masonry materials like empty walls or filled ones with grout.
4) Reinforced concrete shear wall includes the shear wall with reinforced concrete in-situ and prefabricated shear wall. This is one of the most certain methods to resist against the lateral forces. Its location in the plan should be symmetric as much as possible and each floor centroid should be around the center of the rigidity of the shear walls.

Types of shear walls based on the section shape are rectangular shear wall with uniform reinforcement along the section, rectangular shear wall with concentrated reinforcement in two ends of the wall and Dumbbell or L-shaped wall

2. Modeling of laboratory samples

F In order to investigate the shear wall with straight linear section a specific shear wall model whose laboratorial sample has been investigated was used. In this sample the loading has been imposed above the shear wall using the hydraulic jacks as the gradual load with usual loading speed. The loading diagram based on the imposed dislocation by the hydraulic jacks is as following. (Diagram drawing like this article). For each dislocation rate imposed by the jacks the shear wall reaction has been measured and then the force-dislocation diagram is drawn in consecutive periods.

This diagram which is named hysteretic has been used to investigate the seismic behavior of the walls. Generally, to model each structure's part in finite-element software appropriately the features of the applied materials should be defined first. In fact, the existed materials behavior in a finite-element model will have the most effectiveness in the obtained results from the analysis. In this study, the shear wall is considered as a combined structural part that consists of concrete and steel materials. The simulated concrete is considered as the complex materials and different theories on this field approve this claim (ACI-ASCE Committee 325, 1985, UBC91, 1991).

During the bearing stress creation in the concrete, its behavior is according the diagram (drawing based on the existed status) [1] and two regions in the tension-strain area of the concrete are imaginable. The first region is related to the linear and elastic behavior of the concrete which in the tension-strain diagram is linearly started from the coordinate system and ended to the yielding point. In this region the gradient of the tension-strain curve is equal to the elastic module according to E (Young module) which is obtained from the following equation:

$$E=5000\sqrt{fc}\ \text{MPa}$$

The second region of the tension reaches to the yielding amount and in these conditions the concrete is yielded and the tension-strain diagram gets the curve shape. This status continues to end in concrete breaking (Englekirk, 2003).

Another point which should be considered is that the confining effect is under pressure in the tension-strain diagram which should be taken into account in most of the modeling. In fact, confining in the wall of this study is created by the closed stirrups whose confining effect and its effect on the bearing behavior of the concrete has been investigated by Mender. Numerous experiments have shown that in the strain the concrete reaches to about 0.002 of its fc bearing stress and most of the times it reaches to about 0.003 of the breaking stress. In this modeling, the maximum concrete's bearing stress for the cylinder sample was about 45.6 MPa, the concrete's density was 2383 kg/m^3, and the concrete's elasticity was E=36.9 GPa.

Features such as score, distance, yield, and the shape of the stirrups have been presented. In this research, to consider the pressure behavior closer to the real world the proposed equations by Mander have been applied. Based on the presented equation, it can be found that with increasing the lateral confining pressure resulted from the closed stirrups in the concrete's stress region the bearing stress is increased and as a consequence the part's ductility will be more. In modeling the wall of this study, regarding each stirrup marked region, the appropriate stress features with the region's confinement were introduced to software (ABAQUS manual, 2012).

The first region is the confined concrete in the stirrup, and the second one is the confined concrete between the large and small stirrups. The third region is the confined concrete of the first and second regions between the horizontal and vertical reinforcements of two napes. The fourth region which lacks confining is related to the reinforcements covering concrete. Concrete's tension behavior is one of the most effective parameters in the process of concrete material features and this effectiveness has made it so crucial. The concrete maximum tensile strength or the same cracking is calculated as $f_r = 0.6\sqrt{fc}$ which has been presented in concrete codes (Wakabayashi, 1986).

In ABAQUS software to introduce the tension behavior the tension hardening option should be used in which the amount of the tension-stress imposed on the concrete for the tension-strain or tension displacement is defined. In this research, the tension stress-displacement tension definition has been used which has been calibrated in a trial and error process in the stage related to the accuracy measurement and then used in other modeling cases. Diagram drawing under the tension hardening is related to the Draker-Prage breaking and the default amounts.

One of the most important aspects of the concrete damage plasticity materials is the damage parameter. When an element is used to simulate the concrete it should have all of the concrete index features under the loading. As three features of materials have been defined in ABAQUS software, one of them is applied for the different conditions of modeling and loading. In the cyclic loading which is mostly used to analyze the seismic behavior of the structure parts, the concrete damage plasticity model has been proposed. Also, considering the effect of decreasing the stiffness in concrete is among the main features of this materials' model.

Suppose that a concrete element is under the bearing load, it is clear that the bearing strain is also increased because of the bearing stress increasing. Now, if the loading direction gets inversed which was in form of back and force, the same element is under the tension by which the concrete starts getting its mass increased till the cracks are created. In fact, in the strain position of the concrete, a very little stress is borne without cracking and after that it is cracked which results in having the strain increasing and element volume changing.

Now suppose the returning of stress and pressure after the total passing and the present element is under the pressure. In these conditions, the concrete which had already been cracked because of high tension naturally needs the tension cracks to be closed and regain the element rigidity first. During this stage the element rigidity is so low which is introduced to software by the damage parameter defining. In other words, one the main distinguishing and wavy features of the hysteretic diagrams related to the concrete elements to the pinching whose diagrams are clearly observable. In this article considering the similar images of the tension damage in the concrete materials model and calibration of those values with the laboratory sample the contraction could be modeled to a large extent. In modeling discussion another phenomenon in the reinforced concrete behavior like reinforcements sliding and dwelling action by the definition of tension stiffening have been used.

To model the reinforcements' behavior in the concrete the kinematic stiffening model has been used, which is a bilinear curve. The first line gradient indicates the initial rigidity/stiffness of the materials (elasticity module) and the second line gradient indicates the reinforcement repeated hardening. To consider the reinforcement and concrete interaction the embedded element linking method between the reinforcements and elements has been applied.

In this method the degrees of freedom of the reinforcements' elements are deleted and the concrete element is considered as 3D Solid with 4 knots each knot with six degrees of freedom, three displacement degrees and three rotational freedom degrees. The reinforcement element has been considered a type of BEAM which is a linear element with two knots in the end of the line and each knot has three displacement freedom degrees and three rotational freedom degrees. It is worth mentioning that most of the articles have used the truss element with knots and three displacement freedom degrees without rotational freedom degrees to model the in modeling the reinforced concrete elements which regarding a lot of nonlinear parameters resulted from the created crack in the concrete and creating the breaking in the concrete the probability of convergence lack in these conditions will increase, but supposing the beam element this issue is less occurred.

The analysis method by the ABAQUS method is in standard form or the same Newton-Raphson method which is also called implicit method. Also, because of very abrupt questions resulted from the created cracks in the concrete and nonlinear parameters resulted from these phenomena the facilitating methods of convergence like stabilization of viscosity and the energy loss have been used which have been determined with the minimum effect on the accuracy of the results of these parameters. The force-displacement hysteretic diagram in the linear shear wall resulted from analyzing the confined elements model is shown as follow, which compared to the hysteretic diagram obtained from the laboratory sample has a relative convergence (ABAQUS manual, 2012).

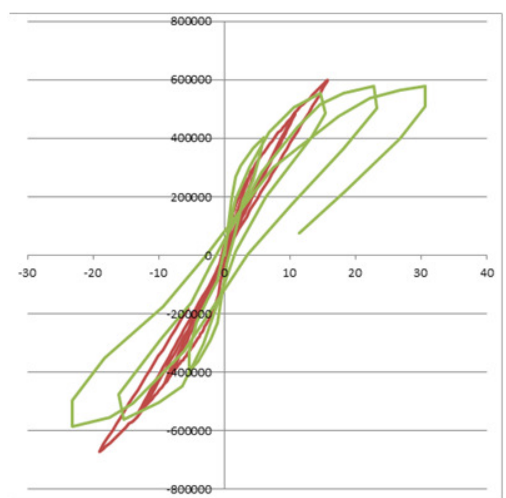


Fig. 1: Hysteretic Diagram of Finite Element *vs* Experimental (N-mm)

As it is observed in this diagram, the contraction effect is significant. Since the area below the force-displacement diagram always indicates the lost energy, it could be found out that contraction has a great effect on the energy loss power in the element. In fact, high contraction indicates the low power of oscillatory energy loss by the investigated element. In the reinforced concrete, contraction is often one of the main wavy features of hysteretic diagram, while in most of the steel elements except for the specific cases such as creating the local crippling in the observed element contraction does not occur.

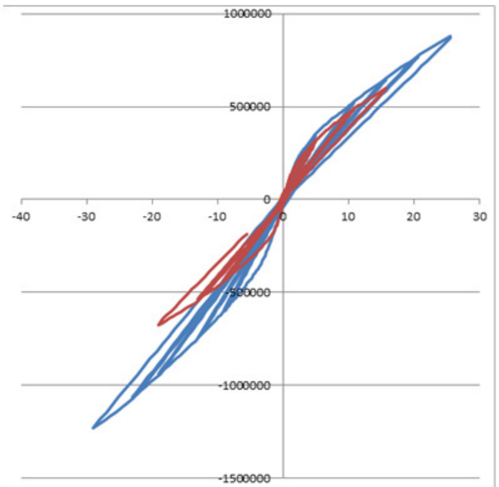


Fig. 2: Hysteretic Diagram of Linear Wall vs L-shaped Wall (N-mm)

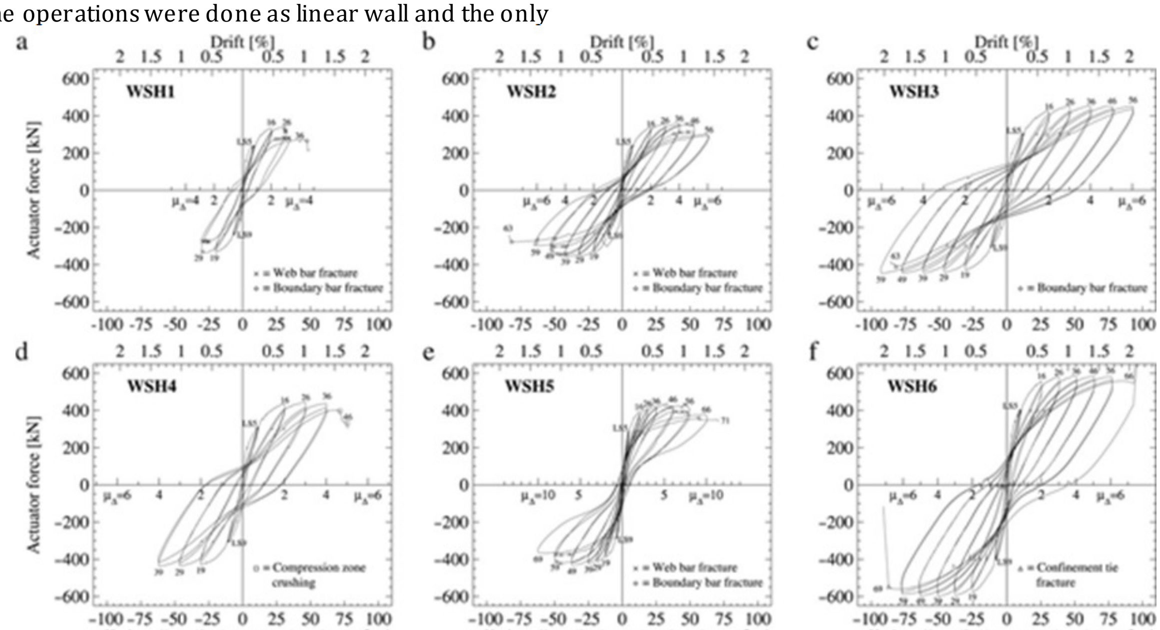
Investigating the hysteretic methods envelopes of two laboratory samples and the confined elements it can be found out that the appropriate convergence has been occurred in modeling which is a result of tension stiffening calibration and also the model's appropriate bearing behavior. After investigating and accuracy measurement of linear wall model the L-shaped wall modeling was followed. In this stage the operations were done as linear wall and the only difference between these two types of walls is in models' drawing. Comparing the L-shaped linear wall with the proportionate dimensions of the linear wall indicates the high strength and the consistent behavior of the L-shaped wall.

The rate of the contraction in the L-shaped wall is close to the linear wall and no remarkable difference between these two walls—regarding the stirrup marking—is seen. However, it is important that the effects resulted from the shear and torsion failure in the corner of the L-shaped wall has not been observed because of the type of the applied element. More exactly it is because of the fact that the parameters can be investigated in the laboratory results.

3. Conclusion

In the dissertation it is concluded that creating the more torsion stress in the corner of L-shaped walls and also the reinforcements' high density are the main disadvantages of these types of the walls which make difficult using of these walls in compared to the linear walls. Instead, stiffness and also high strength of these walls are among the advantages of these walls compared to linear ones. Because of this high stiffness it is recommended to use these types of walls in the central regions of building plan and in case of combining with linear walls the stiffness distribution needs to be created in walls.

Regarding the high stiffness of the L-shaped walls compared to the linear ones, creating the balance between the received force by the L-shaped wall and linear wall should be taken into account in designing the building and the shear walls' layout. In case of linear walls in the plan the combination of these walls with the L-shaped ones should be avoided as much as possible.



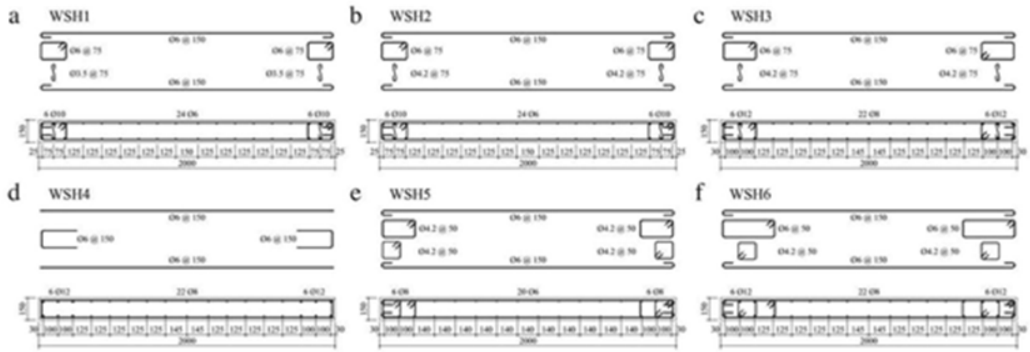


Fig. 3: Reinforced layout in the plastic zone of test units, all dimensions in [mm] (Tahoni, 2004)

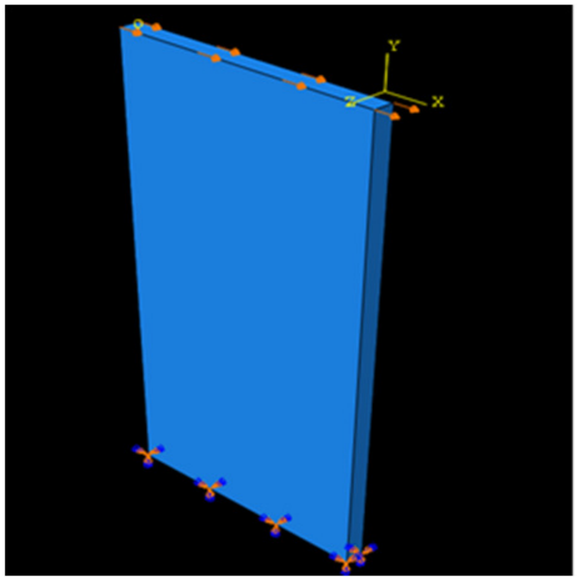


Fig. 4: Loading and Restraint Assignment in Linear Wall

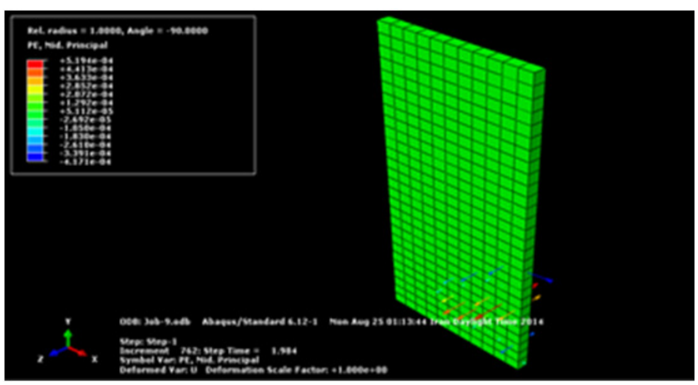


Fig. 5: Mesh Pattern of Linear Wall

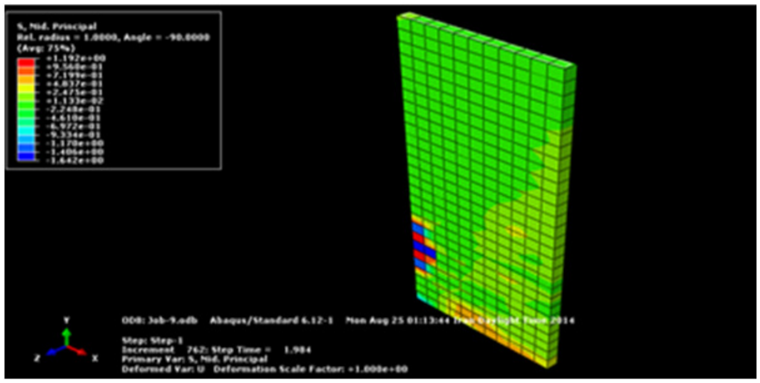


Fig. 6: Output of Principle Stress of Concrete Element in Linear Wall

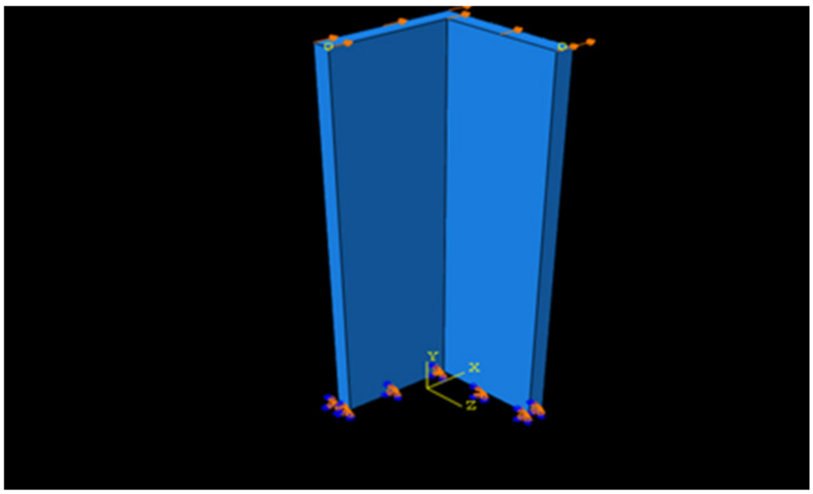


Fig. 7: Loading and Restraint Assignment in L-shaped Wall

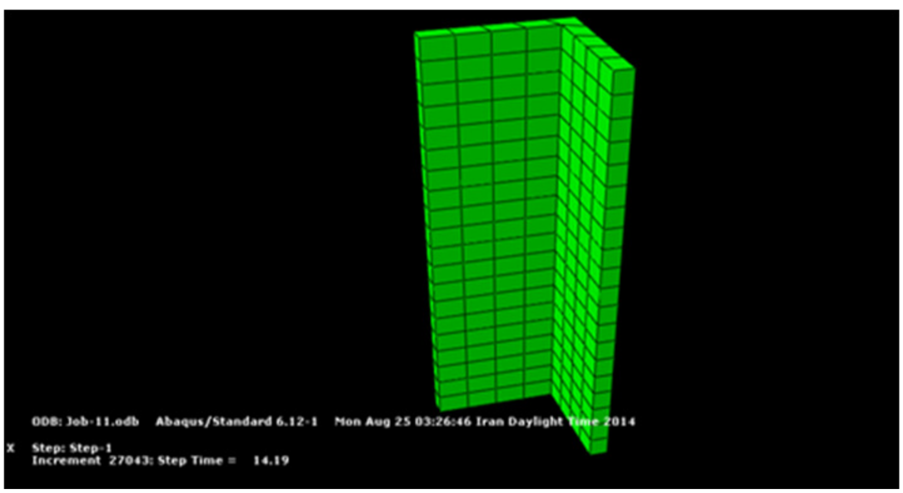


Fig. 8: Mesh Pattern of L-shaped wall

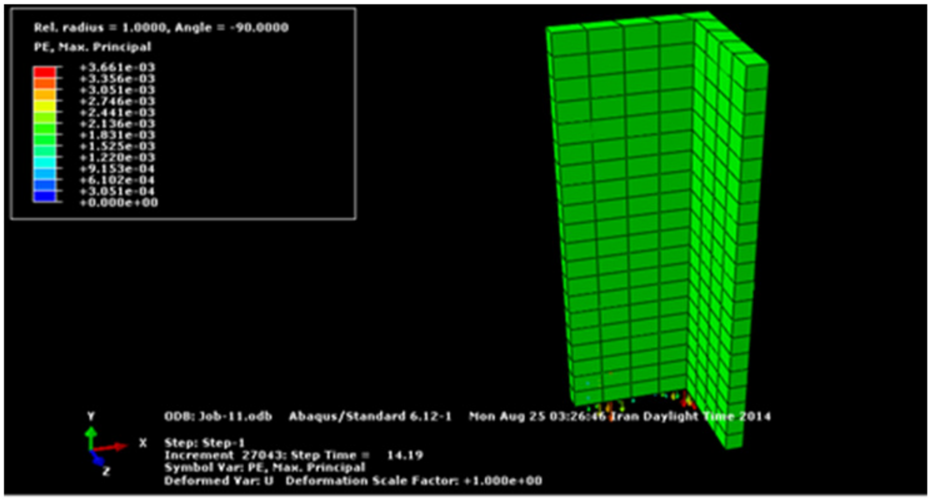


Fig. 9: Output of Principle Stress of Concrete Element in L-shaped wall(initial behavior)

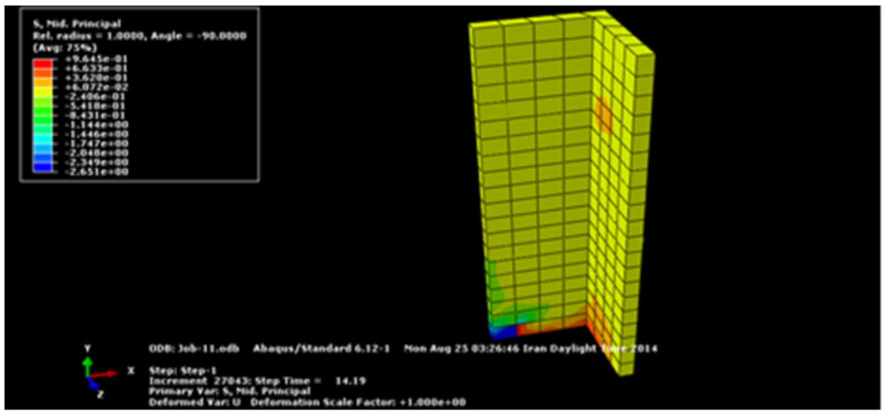


Fig. 10: Output of Principle Stress of Concrete Element in L-shaped wall(final behavior)

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