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Pushover Analysis of Slip formed Load Bearing Wall Panels

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Abstract: The slip formed load bearing wall panel constructing method is very effective in terms of cost and speed of construction. Moreover, it is environmentally friendly, because no river sand is used. In addition, different mix proportions of material give different load bearing capabilities. This method has already been successfully implemented in many medium rise buildings in Sri Lanka. However they were not designed for earthquake loads. Therefore many such structures are susceptible to damage under possible effects of small to moderate earthquakes. This will have huge economic impact in countries like Sri Lanka. Pushover analysis method can be used to study the seismic resistance capacity of structures. This paper discusses seismic resistance capacity of slip formed load bearing wall panels using pushover analysis. The wall panel was modelled using finite element method. Pushover analyses were conducted to examine the behavior of such structures under different boundary conditions. The variation of failure stresses in each node of the finite element model was examined with the help of Rankin failure criterion. The use of Rankin failure criterion is justified since the wall panel materials display brittle behavior. The analytical results showed that the wall panel constructed by this method shows different resistance against earthquake loadings when different material propositions are used.

Keywords: Finite element method, slip-formed method, pushover analysis

1. Introduction

Although, many construction projects are now going on every where, but by day cost of construction material is rising rapidly. Also, a method such as Brick wall construction is not protecting the environment, because of river sand usage. Consequently, in previous decades many research activities were introduced to find the solutions for the above problems.

Composites of cement, crusher dust and coir have been used to build load-bearing walls of building structures in Sri Lanka. In this technique, the walls have been constructed combined with pre-stressed pre-cast columns, in-situ reinforced concrete plinth beams and tie beams. This special construction technique is called slip-formed method. It was introduced in the early 80s' as a low cost and rapid construction technique. It also supports the for protection of the environment because there is no usage of river sand. Moreover, presently, this method of construction is successfully applied through out the island [1] [2].

The material properties of this special composite such as Young's modulus, Poisson's ratio, compressive strength, tensile strength, flexural strength etc have already been studied and the behavior of the structural members due to the various load combinations such as Dead+Live, Dead+Live+Wind, and Dead+Wind have been studied with the appropriated partial safety factors. However, these properties are changing according to cement and crusher dust proportions [3].

Although, Sri Lanka is located in a zone where only few seismic activities have occurred; still there is a certain possibility that an earthquake occurring in the South Asian region can affect the structures built in Sri Lanka. Therefore, it would be useful to check the seismic capacity of wall panels made out of this special composite material [4].

2. Methodology

The push over analysis method is very popular in prediction of structure seismic capacity, because it has a lot of advantages, as it is very easy for computation [5]. This paper presents pushover analysis procedure for determining the deformation behaviour of slip formed wall

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panels. Moreover, the displacement is given in different steps at the top of the wall panels developed using Finite Element method. Also, those wall panels have different boundary conditions.

- Finite Element Models (FEM)

Finite element method is effective in many engineering applications. In this analysis, SAP2000, finite element software was used for developing four different types of FEM [6] [7] [8]. In this study, rectangular wall panels of 2.7m height by 3m wide by 0.254 m width were modelled using finite element method. The Shell elements were used to develop the wall panel and frame elements were used for implementing the rigid beams as well as the rigid columns. These frame elements, pin joints and fixed joints were used for implementing appropriate boundary conditions.

These four FEM were created for exhibiting the wall panels included different boundary conditions and each of the boundary conditions are representing different types of situations in real structure as given in the Figures 1 to 4

The finite element models are illustrating special nodes introduced for transferring moment and forces among the sub divided parts. This technique was implemented for improving the accuracy of the analysis. Furthermore, the rigid beams and the columns were used for implementing different boundary conditions and different material properties of high elastic modulus, zero weight of the material and zero Poisson ratio. Because of that fact, the energy absorption of these rigid members can be neglected. As a result, the total energy can be directly transferred in to wall panel when undergoing to pushover analysis.

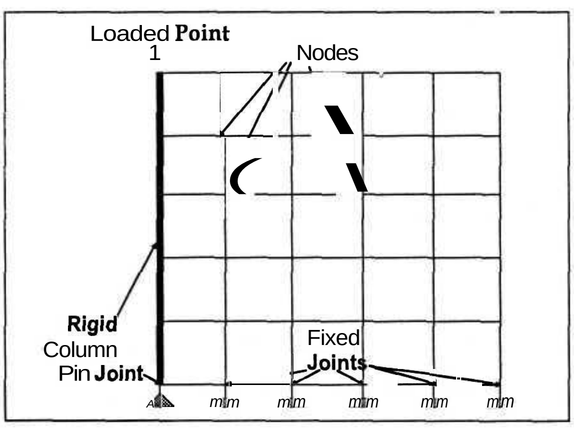

Figure 1. Rigid column with the wall panel (Case 01)

In the Figure 1, the pin joint was implemented to move the rigid column freely, but several fixed joints were implemented for introducing restrain at the bottom of the wall panel. Consequently, in this model, we can measure the seismic capacity of the wall panel consisting of one concrete column support

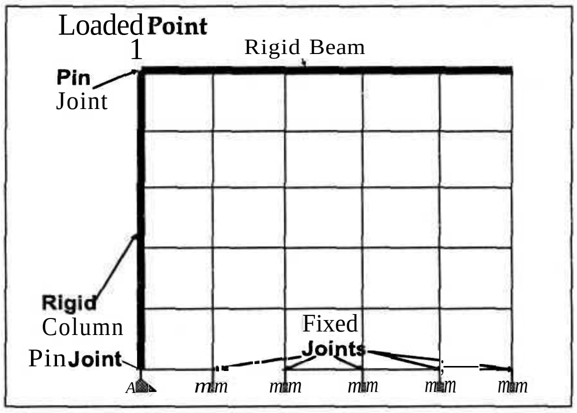

Figure 2: Rigid column and the rigid beam with the wall panel (Case 02)

In the Figure 2, a rigid beams and a rigid column were used. Also, two pin joints were used at two places and several fixed joints were implemented for wall panel to improve the restrain at the bottom. As a result, this model is representing the wall panel with one concrete column and one concrete beam support situation.

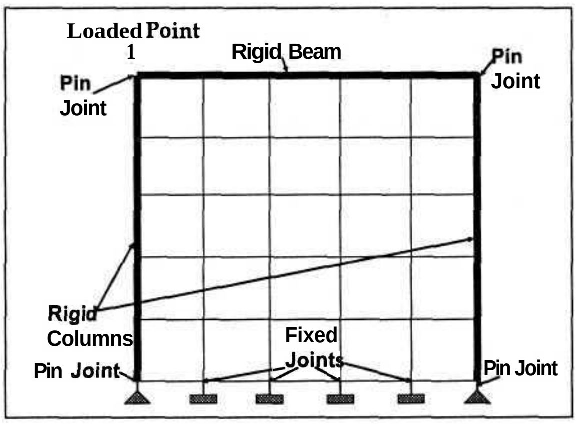

Figure 3: Two rigid columns and the rigid beam with the wall panel (Case 03)

The Figure 3 shows two rigid columns as well as one rigid beam. Four pin joints were implemented at the end of these frame elements to move the system under the analysis very easily. Moreover, several fixed joints were implemented for the purpose described under the Figure 2. This model is representing the wall panel consisting of two concrete columns with a concrete beam.

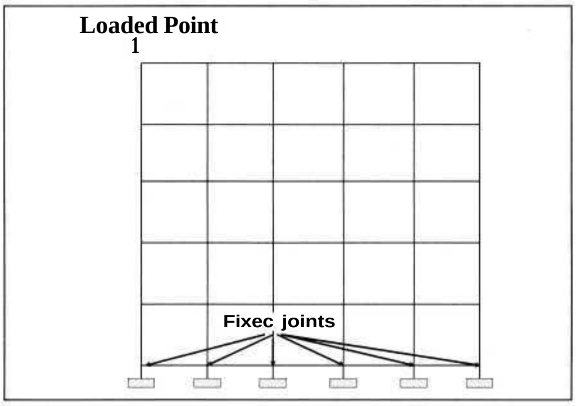

Figure 4: Without any rigid elements with the wall panel (Case 04)

The Figure 4 is representing the wall panel without any other structural supports. The fixed joints were implemented for the purpose mentioned under the Figure 2. Further more, this case was selected, because this is the most critical case identified in real practice.

Having been applied different material proportions (given in Table 1), each model was studied when subjected to push over analysis.

Table 1: Material properties of different material proportions

Mix Proportion	1:8	1:10	1:12
Splitting Tensile Strength/ (N/mm²)	0.574	0.402	0.315
Unit Weight/(kN/m³)	18.88	18.54	18.2
Young's Modulus/(Gpa)	10.65	6.90	5.98
Poisson's Ratio	0.12	0.15	0.17

3. Analysis

The Pushover analysis was done. The incremental horizontal displacements were applied at the joint 1 as shown in the Figures 1 to 4.

The safety of the wall panels were studied using a failure criterion based on the stresses exhibiting in the wall panels. The material of the wall panels behaved as brittle. Therefore, the Rankin failure criterion was employed to examine the state of the panels. The Rankin failure criterion for the X and Y directions are defined as given below.

$$S1 = \frac{(Sxx + Syy)}{2} + \sqrt{\frac{(Sxx - Syy)^2}{4} + Sxy^2} \quad \text{.......(1)}$$

$$S2 = \frac{(Sxx + Syy)}{2} - \sqrt{\frac{(Sxx - Syy)^2}{4} + Sxy^2} \quad \text{.......(2)}$$

Where, S_{xx} is x directional stress, S_{yy} is y directional stress and S_{xy} is x and y directional stress. For the non-failure occasion $|S1| \leq S$ and $|S2| < 5$ where S is material failure stress [9][10].

4. Results and discussion

The failure stresses were examined using the equations (1) and (2) for different material proportions and failure points were determined with the help of splitting tensile strength of each material proportion as shown in Table 1. As a result, the maximum horizontal displacements of each case were obtained and results are given in Table 2.

Table 2: Maximum displacements of each case with the different material proportions

Material Proportions	Maximum Displacement/(mm)			
	Case 01	**Case 02**	**Case 03**	**Case 04**
1:8	**15.3**	**15.4**	**15.5**	**15.3**
1:10	**16.8**	**17.0**	**16.8**	**16.5**
1:12	**15.1**	**15.8**	**15.0**	**14.8**

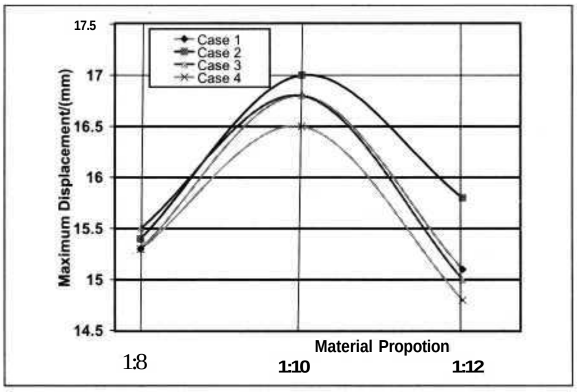

*Figure 5: Maximum **Displacements/ (mm)** Vs Material Proportions*

According to above results, we can say that the wall panel constructed with 1:10 material ratio has more seismic resisting capacity than other material ratios such as 1:8 and 1:12.

5. Conclusions

The slip formed construction method has several advantages such as cost effectiveness, rapid construction, low skill labour usage and environmental friendliness. In this study, the Pushover analysis method was used to check the lateral deformation capacity of slip formed wall panels. The results showed that the wall panel constructed with 1:10(cement: sand) material ratio has more earthquake resisting capacity than the other material proportions such as 1:8 and 1:12. In addition, the cost of construction is concerned, the wall panel constructed using 1:10 material proportion is more economical than 1:8, because of low cement demand.

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