THE EFFECT OF ORDER OF HINGE FORMATION ON DEFORMATION CHARACTERISTICS OF A PROPPED CANTILEVER

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Abstract: **Push over analysis is a popular tool for seismic performance appraisal of the structures. Notwithstanding the efforts made to enhance the capabilities of the method, much needs to be done to obtain load deformation characteristics as there are unresolved issues to be addressed in connection with geometry and material modeling which have been brought to light by the differences between analytical predictions vis-à-vis experimental results. Various geometric and material modeling techniques have been tried to close the gap between analysis and experimental results by way of models for plastic hinge lengths and locations, uncertainties in material and geometry by way of stochastic formulations. Though the load capacities predicted by analysis have been accomplished in close agreement with experiments, mismatch with deformations persist. One possible cause for this mismatch is the sequence of formation of hinges which greatly influences the drift. This paper illustrates the importance of consideration of sequence of hinge formation in push over analysis.**

Key words: **Push over analysis, post elastic behaviour, load deformation, hinge formation, stochastic formulations.**

INTRODUCTION

The basic philosophy of earthquake states that the structures withstand frequent minor earthquakes without any damage, resists moderate earthquakes without significant structural damage though some nonstructural damage occurs and aims to withstand major earthquakes without collapse. That is, structures behaves elastically for earthquakes of magnitude less than design based earthquakes(DBE), elasto-plastically for design based earthquakes and plastically for maximum considered earthquakes(MCE) without collapse. The structures subjected to earthquake loading have to be essentially analyzed by nonlinear static analysis to capture the behavior of structures under seismic effects. It has been widely accepted that the push over analysis provides the nonlinear behaviour of the structure that cannot be obtained by linear static and dynamic analysis procedures. The push over analysis is widely used due to its simplicity in predicting the performance of the structure. However this method is yet to be refined to get the analytical predictions closer to the actual results. The effect of plastic hinge properties in nonlinear analysis has been studied by many researchers and numbers of attempts have been made to understand the mismatch of analytical investigation with actual push over analysis results and they have hardly considered the sequence of hinge formation and its effect on structure's load deformation characteristics. This study illustrates how the order of hinge formation influence the deformation characteristics of a structure. A propped cantilever with concentrated load at the mid span is considered for the analysis and deformation characteristics for different order of hinge formation have been obtained.

LITERATURE REVIEW

An overview of literature on the state of the art has been compiled and reviewed as follows.

The limitations of Push Over Analysis have been highlighted by **Helmut Krawinkler and G. D. P. K. Seneviratna(1998)** in their technical note "Pros and cons of a push over analysis of seismic performance evaluation". The basic concepts on which the pushover analysis can be based have been summarized and also the disadvantages of Push over analysis have been discussed. Its foremost advantage is that it encourages the design engineer to recognize important seismic response quantities and to use sound judgment concerning the force and deformation demands and capacities that control the seismic response close to failure, but it needs to be recognized that in some cases it may provide a false feeling of security if its shortcomings and pitfalls are not recognized. They have concluded that pushover analysis is approximate in nature and is based on static loading. There is also a limitation in the load pattern choices. Thus in selecting load patterns and in interpreting the results obtained from selected load patterns, decision has to be taken by considering ground motion and inelastic dynamic response characteristics of the structure.

Mehmet Inel et al(2006) has studied the "EFFECTS OF PLASTIC HINGE PROPERTIES IN NONLINEAR ANALYSIS OF REINFORCED CONCRETE BUILDINGS" in which observations were made to study the difference between the results of push over analysis due to default and user defined non linear component properties. To represent low- and medium- rise buildings four- and seven-story buildings are considered. Plastic hinge patterns of the 4 and 7 story frames are compared at the different levels of roof displacements to provide information about local and global failure mechanisms in the structure.Beam and column elements are modeled as nonlinear frame elements with lumped plasticity by defining plastic hinges at both ends of the beams and columns. The Observations were declared that user defined hinge model is better than default hinge model in showing the non linear behavior of the structure.

A. Eslami et al (2012) have studied “the effect of plastic hinge relocation in RC buildings using CFRP”.An 8-story intermediate RC frame was selected and the effects of CFRP retrofits on the seismic response of the structure were elaborated. They have focused on the relocation of the plastic-prone region away from the column faces and out into the beams. The composite materials were used to generate additional flexural stiffness at beam to column connections and is calculated by a comparison of the moment-rotation of CFRP retrofitted and original joints obtained from the finite element analysis. The analysis results suggested that a rehabilitation design as depicted combined with the strong-column weak-beam design philosophy would improve the seismic performance of structures significantly. This study had shown us that, a weak column-strong beam condition was found resulting in a column side-sway failure mechanism. This in turn, compromised the seismic improvement of the frame through the plastic hinge relocation technique. However, the plastic hinge relocation technique improved both the lateral resistance and the displacement of the frame substantially.

The literature reviewed shown us that even though the push over analysis provides expected performance of the structure under ground motions, it has to be fine-tuned to obtain more accurate results.

OBJECTIVES AND PROBLEM DESCRIPTION

The load deformation curve obtained from nonlinear static analysis for various structures have failed to match the actual deformation characteristics of the structures. The change in sequence of hinge formation which occurs most of the times may be one of the reasons for this. For example in a propped cantilever, the collapse mechanism requires two hinges to be formed. Generally, first hinge forms at the support and with increase in load, second hinge forms below the load. But if there is an upward displacement at the propped end, the moment due to this displacement hinders the formation of first hinge at the support. Therefore the first hinge forms below the load and with increase in load the second hinge forms at the support and completes the mechanism. The probability of this change in sequence of hinge formation greatly controls the load-deformation characteristics of the structural element. To illustrate this, a propped cantilever with concentrated load at mid span has been considered. The load displacement curve has been obtained for incremental loads. The procedure has been repeated by assuming an upward displacement of 2mm at the propped end. The load deformation characteristics obtained for both cases have been compared and observed the changes and discussed.

NONLINEAR ANALYSIS OF PROPPED CANTILEVER

A propped cantilever AB of Span ‘l’ has been considered for the analysis as shown in the figure 1.The section considered is ISMB 300 @ 46.1 kg/m which has the following properties.
Sectional modulus Z_x = 599 cm^3
Plastic Section modulus Z_p = 683 cm^3
Shape Factor = 1.14
Elastic modulus, E = 200 GPa
Yield moment **M_y = 149.75 kN-m**
Plastic moment **M_p = 170.72 kN-m**
For this example a span of l = 2m has been considered and the collapse load is given by

$$W_c = \frac{6Mp}{l} \text{---(i)}$$

Therefore, W_c= 512.145 kN-m
To observe the changes in displacement characteristics the following two cases are considered.

- i) Propped cantilever loaded at mid span and
- ii) Propped cantilever with an upward displacement of 2 mm at propped end.

The corresponding moments and displacements have been determined for incremental loads for both cases. In case (i), first hinge formed at the support and corresponding load was 455.24 kN and displacement is 1.93mm. After first hinge formed at the support, the beam will become determinate and behaves as a simply supported beam as the support is free to rotation. So that displacement due to rotation also will be added with displacement due to additional load, so that the change in the rate of change of displacement is observed till it reaches the collapse load and second and final hinge formed below the load at collapse with a maximum displacement of 3.58mm.Table 1 shows the moments and displacements for the propped cantilever incrementally loaded till it reaches the collapse load and the required two hinges were formed.

The moments and displacements for second case in which an assumed upward displacement is assigned, have also been mentioned in the table 1. Here the moment due to displacement will be countering the moment due to load, therefore moment at load or at mid span moment reaches the plastic moment first, So that the first hinge formed at the mid span and second hinge at support in this case. The corresponding load and displacement at mid span while the first hinge formed at the mid span is 463.7 kN and 2.15mm respectively. Subsequently, the displacement due to rotation at hinge (at mid span) also will be added along with the displacement due to additional load. The second hinge formed with a maximum displacement of 4.32mm. The load displacement curves have been plotted for both cases and compared as shown in figure 2.

RESULTS AND DISCUSSIONS

In first case, first hinge formed at the support at a load of 455.24 kN where the moment reaches M_p, the plastic moment and before the span moment reaches M_p, there is 46% increase in displacement. However this increase in displacement between first and second hinges in second case is more than 50% and even the displacement is 17% more in this case. In first case first hinge formed at support for 455.24 kN load and corresponding deflection was 1.93mm whereas in the second case first hinge formed at the midspan at a load 463.7kN and corresponding displacement was 2.15mm.

The maximum displacement in first case is 3.58mm and that in second case is 4.32mm which shows that the beam becomes flimsier in second case where an upward displacement of 2mm at propped end is assumed and created. Even though the collapse load is same in both cases , the sequence of hinge formation changes in both cases as shown in table 1. The displacement path and maximum displacement attained before failure is different in both cases. The Second case shown more displacement before failure for about 17%.This is because, the cantilever in which hinge formed first at the midspan becomes more flexible as the structural element becomes a cantilever on one side and suspended beam on the other side which makes that flimsier than that in the former case.

CONCLUSIONS

In this study the deformation characteristics of the propped cantilever for different sequence of hinge formation have been observed by conducting a nonlinear static analysis for incremental loading. It has been clearly indicated that the sequence of hinge formation changes with some unexpected changes in the structure. This changed sequence of hinge formation greatly control the deformation characteristics of the structures. The deformation path may become different if there is any material and geometric variations in the structure even it is smaller. There are some chances that the structures may accommodate more deformations, if these variations are friendly in nature. However creating that positive variations, demands a number of trial and error exercises. So that it clearly shows that the deformation characteristics are controlled by change in order of hinge formation in the structures. Further studies in this area may lead us to get the bounds on performance characteristics of structures which are more close to reality.

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FIGURES AND TABLES

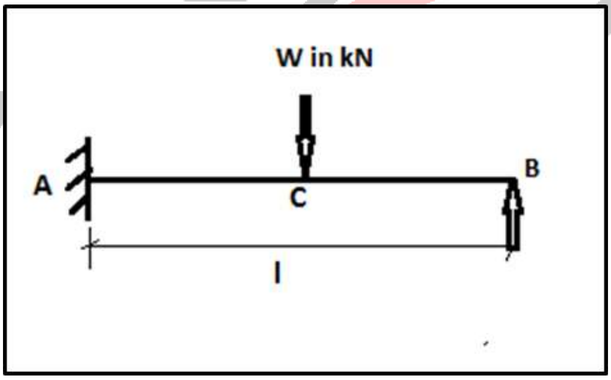

Figure 1.Propped cantilever with concentrated load at mid span

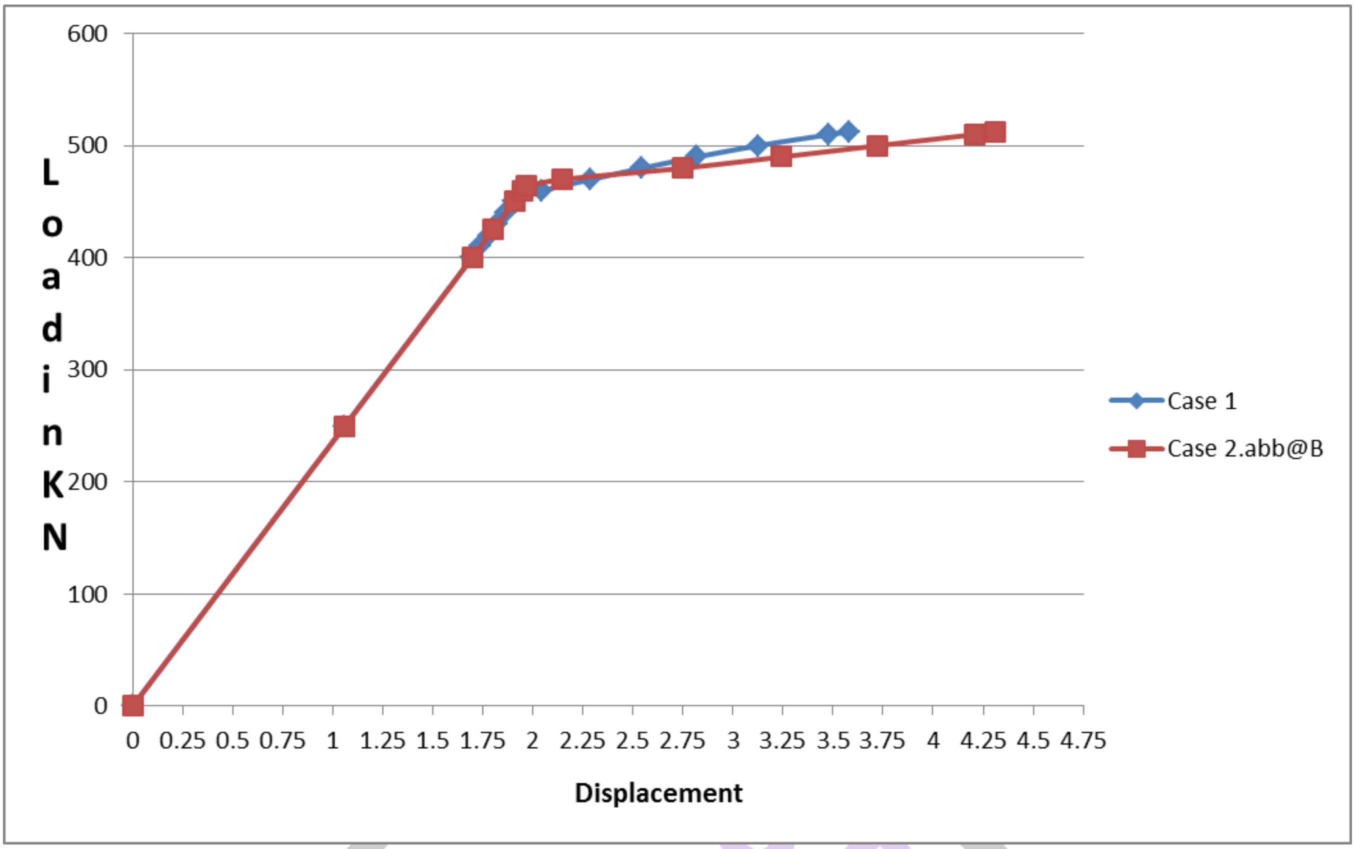

Fig 2. Load displacement curve for different sequence of hinge formation

TABLE 1. MOMENTS AND DISPLACEMENTS

Case (i) Cantilever with no aberrations				Case(ii) Cantilever with an aberrations at propped end		
Load in 'kN'	**Moments in 'kN-m'**		**Max Displacement Δ in 'mm'**	**Moments in 'kN-m'**		**Max Displacement Δ in 'mm'**
	at 'A'	**at 'C'**		**at 'A'**	**at 'C'**	
250	93.75	78.125	1.06	42.13	103.94	1.06
400	150	125	1.69	98.38	150.81	1.69
410	153.75	128.125	1.74	102.13	153.94	1.74
420	157.5	131.25	1.78	105.88	157.06	1.78
430	161.25	134.375	1.82	107.76	158.01	1.82
440	165	137.5	1.86	109.63	160.19	1.86
450	168.75	140.625	1.91	113.38	163.31	1.91
455.24	170.72	142.2625	1.93	117.13	166.44	1.93
460		144.6425	2.04	120.88	169.56	1.95
463.7		146.220	2.11	122.27	170.72	2.15
470		149.6425	2.29	128.57		2.75
480		154.6425	2.55	138.57		3.24

490		159.6425	2.82	148.57		3.72
500		164.6425	3.12	158.57		4.21
510		169.6425	3.48	168.57		4.29
512.145		170.72	3.58	170.72		4.32