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Research Article

Investigation of Progressive Collapse in Cable-stayed Bridges

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Abstract

Today, controlling of structures' progressive collapse decreases damages while natural and unnatural events happen. This issue requires deliberation and consideration for cable-stayed bridges which their utilization in the country is going to increase, so by taking previous surveys into consideration, the best design for the cable-stayed bridge is gained. In this study, the structure's progressive collapse is investigated by alternative load path method. In this method there is an effort to make certitude about the appropriate joint between vertical and horizontal components, in a way that the structure has the ability of load transfer with the elimination of any components of the structure. In order to control this phenomenon in the potential state, destruction of the bridge's elements is evaluated by linear and non-linear static and dynamic processes. In this survey, first the mentioned cable-stayed bridge with assumed geometrical characteristics and materials is designed two-dimensional by relevant regulations. This study and design is performed by SAP2000 computer program and then the designed system's response to the progressive collapse is controlled by static and dynamic methods. But the ultimate purpose of this research is to study geometrical changes of the design such as changes in horizontal distances of cables and changes in pylon altitude or altitude-to-span ratio and the effects of these factors in the mentioned progressive collapse and to compare them. By investigating this research models under dead load, we came to the conclusion that when two cables of the structure are destroyed as a result of breaking away, force redistribution occurs and forces in all the cables are increased. This increase can be up to 1.5 times more and causes forces to exceed the limit which the cables are designed for and therefore it causes destruction of the cable and the structure. But in general the structure is less likely to proceed to the progressive collapse as a result of gravity loads.

Keywords:

progressive collapse, cable-stayed bridge, gravity loads, destruction

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1- Introduction:

According to the developments of structure science, construction of bridges with very large spans has become possible in recent years and there has been a rise in usage of these bridges. Today, cable-stayed bridges with original spans of about 1000 meters (Tatara bridge in Japan and Normandie bridge in France [1]) have been constructed and used [2]. Cable-stayed bridges are one of the most suitable and economic bridges for passing the large spans. Because of the presence of flexible cables in the basic structure, they indicate non-linear geometric behavior. Today, cable stayed structure’s movements can be classified into two categories of static and dynamic deformation. Static movements are caused by softly imposed heat or weight load and long term alterations of wind forces. Dynamic movements related to time-dependent dynamic forces are seismic acceleration, influence of short term alterations of wind, explodes and vibrations of machinery passing the bridge. According to the nature and high flexibility of cable-stayed bridges with large spans, this kind of structures has inherent non-linear behavior and their non-linear behavior should be considered in all kinds of static and dynamic analyses. Some of the reasons of non-linear behavior in cable-stayed bridges are bulging of the cables, influence of pressure head, and interaction of pressure axial force with bending moment in towers, deck’s basic beam and effects of relatively large deformations. In this survey there is an effort to simulate and evaluate seismic behavior and the degree of vulnerability of cable-stayed bridges under progressive collapses by Finite-element method. Therefore, the effect of different factors such as basic tension of the cables, non-linear effects, arrangement effects of the cables, the effect of tower-deck joint type, type of analyze effect, disharmonic stimulation effect, damping effects and … have been studied in this survey.

2- Problem Statement

Assurance about the structure has been under consideration as a principle for engineers who are responsible for designing civil projects. One of the mechanisms that have been paid much attention in recent decades is called progressive collapse. Whenever one or some of the components of a structure suddenly tear apart and then the structure is going to be destructed progressively, in this situation every load distribution brings about the breakage of other structural elements, until a new state of balance is attained when the whole structure or part of it is destroyed.

Recently it has been proved that in order to prevent progressive collapse, unusual loads need to be considered in the structure’s design. Structural companies like Ronan Point and Alfred P.moorah and World Trade Organization have presented destructive results of progressive collapse. According to growing terroristic acts in the future, decreasing progressive collapse should be considered in the structure design.

Progressive collapse is a kind of structural collapse which is started by structural damage and gradually increases like a chain and then contains an extensive volume of the structure. From the annalistic view, progressive collapse is a dynamic process and it is created by internal energy arising from the imposed damage to a structure member. This will destroy pressure balance of other members so the structure is facing problem for retaining its’ balance. According to presented approaches by Leindecker and Ellingwood design models present following methods to construct structures with decreased progressive collapse. Knot pressure method (indirect design), resistance spot method (direct design) and load path method (direct design) are simple processes simulating influences of available progressive collapse. Bridges in comparison to buildings are horizontal structures which are expanded in one axis, so their destruction mechanism is different. Currently the issue of progressive collapse, in spite of its' significant impact on huge bridges is not paid attention carefully. Cable-stayed bridge is the only bridge whose destruction is paid attention. The destruction arises from progressive collapse of small points in the cables and as a result, less resistance is created against accidental excess loads of transportation means or terroristic acts. Destruction of every cable imposes excess loads on adjunct cable and brings about the breakage. In addition, the basic beam will be under pressure and destruction of the cables will reduce its' resistance. In designing cable-stayed bridges, it is usually suggested that sudden breakage of one cable should not cause structural instability and should not be limited to destruction of load carrier cable. (PTI, 2001, FIB, 2005)

PTI (2001) represent a complete guidance while destruction of the cables which is concerned with load operation and accidental factors. Two methods of load operation are suggested. Static simplified methods which are: studying the structure with destructed cable by considering live and dead loads putting together with static performance and dynamic force of confined cables. Also PTI (2001) permits usage of dynamic analysis of the structure against destruction of the cable. But there are limited procedures in relation to the mechanism of dynamic analysis and designing comprehensive structural arrangements. For developing design codes related to progressive collapse of cable-stayed bridges researches about simulated processes of progressive collapse are compared together.

In this survey, the structure's progressive collapse has been investigated by alternate load path method. In this method there is an attempt to make sure about the suitable joints between vertical and horizontal components, in a way that the structure will have the ability of load transfer by the elimination of every component in the structure.

In order to control this phenomenon we evaluated bridge elements destroy with the aid of linear, nonlinear static process and linear and nonlinear dynamic process. In this study at first we design a 2 dimensional cable stayed bridge with assumed geometrical features and materials by considering related regulations. This study and all the designing are done by SAP 2000 software. Afterwards by using static and dynamic methods we control the response of designed system for progressive collapse. The final purpose off this article is to investigate, compare and study the geometrical changes of the design including variation in horizontal distance of cables, Pylon height, and height to span ratio and these factors' effect on progressive collapse.

Nowadays controlling the structures progressive collapse is one of the most important reasons of their damage reduction in natural and unnatural events. Since the use of cable stayed bridges is increasing in our country, we need to think and study this subject and consider previous designs to choose the best design for cable stayed bridges. This study aims to get to a certain level of confidence and present initial design to reduce the probability of progressive collapse in designing cable-stayed bridges in a way that it resists sudden collapse and decreases financial and life loss.

In this research we aim to answer the following questions:

1- How is progressive collapse in cable-stayed bridges?
2- Which analytical method helps to study this collapse?
3- How do geometrical changes affect a bridge progressive collapse?

3-Background

Fleminge was of the first people who heeded to cable stayed bridge dynamic behavior [2, 3]. He investigated the behavior of Norbuke short span bridge in Germany by using cable and beam elements based on a 2-D mathematical model and studied the linear and nonlinear response of this bridge under Elcentro dynamic behavior.

Among other people who proceeded to linear and nonlinear behavior, 2-D and 3-D models we can name Abdel-Ghaffar and et al [3, 4, 5 and 6]. Nazmy and Abdel-Ghffar studied and compared dynamic response of two bridges with main span of 335m and 670m [4, 7]. The results showed a great difference in linear and nonlinear dynamic response of the bridge with larger span. Besides they compared the dynamic loading effect on the response of mentioned cable stayed bridges and found different responses. Also the loading was performed as ground excitation uniform and non-uniform loading on two models under dynamic behavior excitation. According to the findings the non-uniform excitation studies had a larger response in relation to uniform excitations. The effect of viscous dampers and structure and soil interaction on the dynamic response of static cable stayed bridge with the main span of 274m was studied by Sonji [8, 9]. He examined the effect of several vibrations on a soil as deep as 25m with 4 diverse layers by means of soil modeling and the help of damper and spring. The result indicated different response in exchange for soil type and the studied vibrations [9]. In order to reduce the vibrations and based on inactive controlling by Elastoplast dampers, Abdel-Ghaffar and Ali did a research on two types of bridges with the main span of 335m and 670m [10]. They put three basic separators in abutments and tower joint point to deck. The seismic analysis was executed by step to step integration based on 2-D models and deck simulation with beam element. The results revealed the using seismic separators in static cable stayed bridges helps reduction of seismic response and so tower's base shear. Also utilizing inactive seismic controlling systems has a significant role in reduction of bridge deck dislocation response. Takahashi also studied the site effect heeding to three types of soil: hard, medium and soft on a cable stayed bridge with main span of 219m under seismic loading in two vertical and horizontal directions [11]. A review on mentioned studies demonstrates that most of the researches focused on nonlinear behavior or structure's soil interaction. In many of the above researches bridge deck is modeled using beam element. In current study meantime modeling the deck by using shell elements and box model, we study its nonlinear behavior under clear dynamic analysis. This model makes possible to investigate the behavior after deck's local buckling. The effect of seismic wave's collision angle also has been checked parametrically by considering cable vibrations in bridge dynamic analysis.

In the following we will proceed to study and examine progressive collapse in cable stayed bridges in several recent years.

In 2012, Cao Gao Jiang and et al [12] studied the different static and dynamic processes in analyzing the progressive collapse of cable stayed bridges and the result from evaluating complete destruction of cable showed that the effect of progressive collapse in cable stayed bridges will decrease when the destroying cables are adjacent to pylon.

In 2010, Yan and Chang [13] presented a probable framework in which the amount of vulnerability of the cable stayed bridges was examined quantitatively in terroristic attacks. Then they presented a technic based on plastic limit state analysis for evaluating a single pylon cable stayed bridge.

In 2008, Wolff and Starossek [14] investigated structural reaction of Cable stayed bridge in relation to destruction of one cable using dynamic analysis including large dislocations. They also studied the effect of seismic fluctuations of cable projection and the amount of humidity.

In 2007, Zoli and Steinhouse [15] presented a sample relating to structure resistance against progressive collapse in a new bridge with two cable destruction in USA north east. Therefore in the present study with regard to previous researches, we heed to geometrical changes and diverse dislocations in a cable stayed bridge to gain the best level of study and investigate and compare it with past researches. Then we present the best level for constructing a cable stayed bridge.

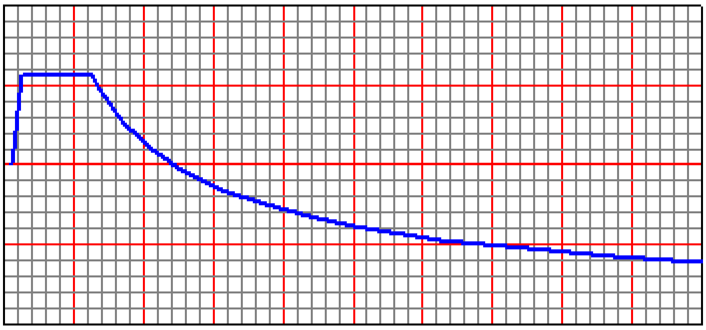
In 2012, Koshtehgar and Miri [16] investigated the nonlinear dynamic behavior of static cable stayed bridge with large span and box deck parametrically. In this research a static cable stayed bridge with box deck and the length of 1255m was studied and simulated by finite element method. We studied seismic wave’s collision angle considering cable vibration in bridge dynamic analysis parametrically. Seismic excitations were exercised on a support uniformly and non-uniformly.

4- Research method

In this article some joints of the V (shear) type and M (bending) type are allocated to pylon and also we used uniform triangle loading. We also study the findings related to regulating methods like FEMA.

Modal analysis has two types in this research. The first type is analyzing the Eigen vector and the second type is analyzing Ritz vectors. We take benefit from 2800 standard design spectrum and a scale coefficient is also implemented for it.

Figure 1(spectrum 2800)



According to regulation we used three types of earthquake. We desire the maximum response of structure under each of these three records. In here we used Bam earthquake accelerograph. All of the three elements are scaled to their maximum acceleration in Seismosignal software and in SAP we exercised some coefficients. Figure 2, 3 and 4 shows theses accelerographs.

Figure 2 (accelerograph number 1)

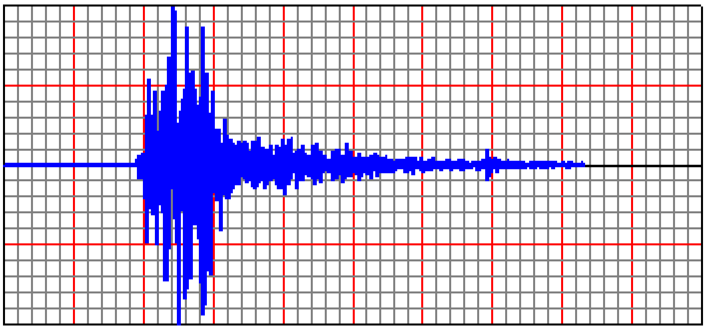


Figure 3 (accelerograph number 2)

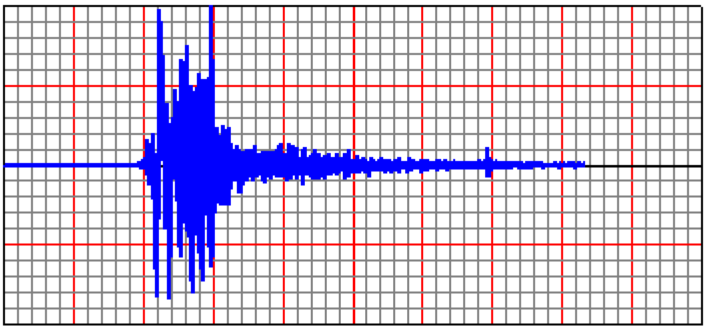
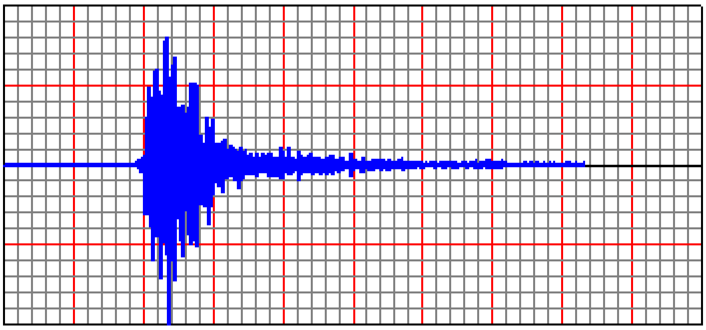


Figure 4 (accelerograph number 3)



4-1 static linear analysis

4-1-1 models 1 and 2 under dead load

Under impression of gravity load s such as dead load it seems impossible that progressive collapse happens in the structure. However, axial forces arising from dead load are shown below. These loads are created in the cable of both structures: models 1 and 2.

Figure 5. axial force in cable 1 model 1 under dead load

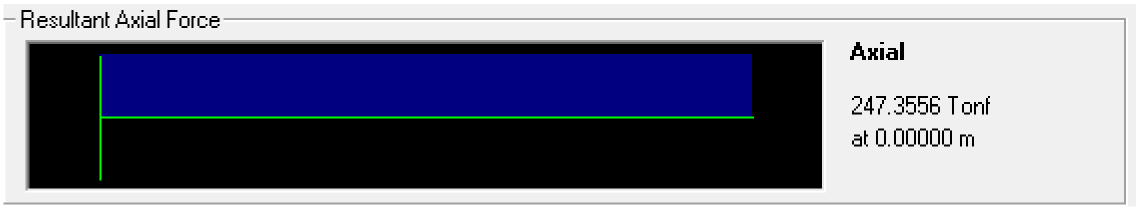


Figure 6. axial force in cable 1 model 2 under dead load

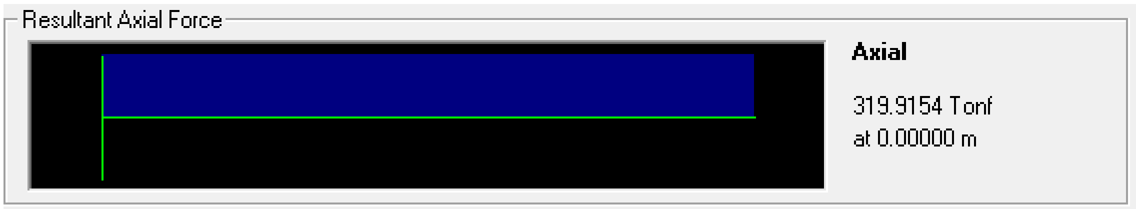


Figure 7. axial force in cable 2 model 1 under dead load

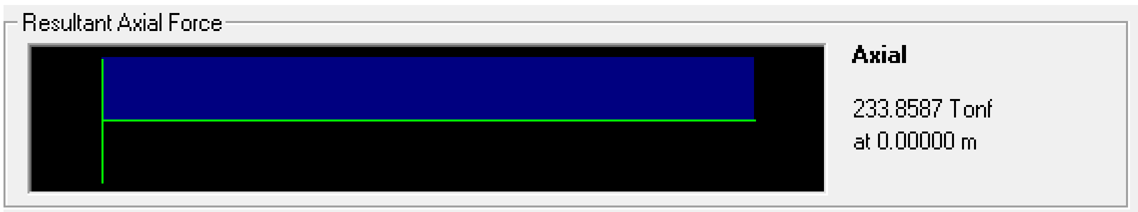


Figure 8. axial force in cable 2 model 2 under dead load

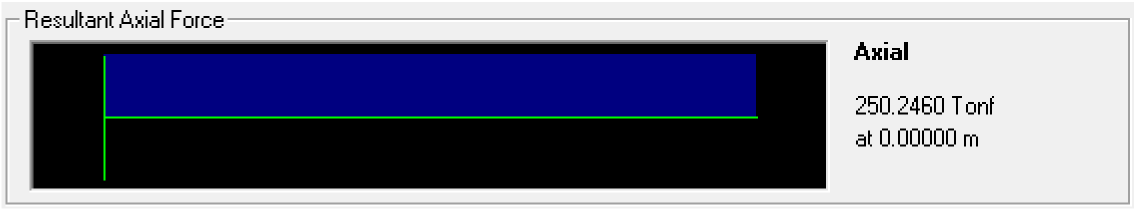


Figure 9. knot 17 dislocation in model 1 under dead load

Joint Object 17		Joint Element 17	
	1	2	3
Trans	**0.00127**	**0.00000**	**-1.06374**
Rotn	**0.00000**	**-0.07580**	**0.00000**

Figure 10. knot 17 dislocation in model 2 under dead load

Joint Object 17		Joint Element 17	
	1	2	3
Trans	**0.00185**	**0.00000**	**-1.11542**
Rotn	**0.00000**	**-0.07992**	**0.00000**

We observe when two cables are dismantled because of break; force distribution still happened and forces in rest of the cables increases. This increase can be up to 1.5 times more and causes forces transgress from the certain forces that the cable was designed for and results in cable destruction and finally structure collapse. Generally the possibility that the structure goes toward progressive collapse because of gravity loads is small as well dislocation in model 2 increased in relation to model 1.

4-1-2 under wind and earthquake load

We exposed both models to static loads equal to the earthquake and wind. We expect that changes in axial forces and dislocations are ignorable since these two loads are exercised to the structure in horizontal direction and cable cut effect is lower under this condition in relation to other conditions. In figure below we presented tension and dislocations amount for cables 1, 2 and knot 17.

Figure 11. Axial force in cable 1 and in model 1 under wind force

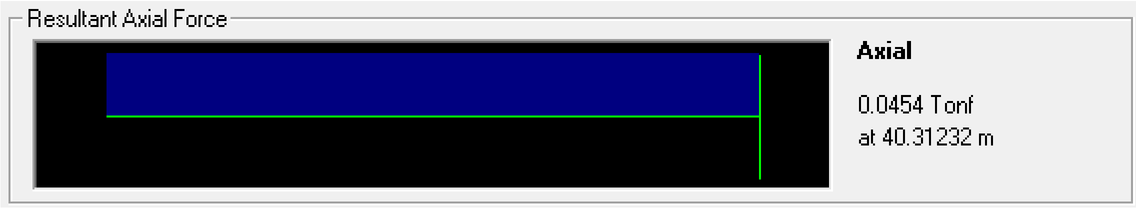


Figure 12. Axial force in cable 1 and in model 2 under wind force

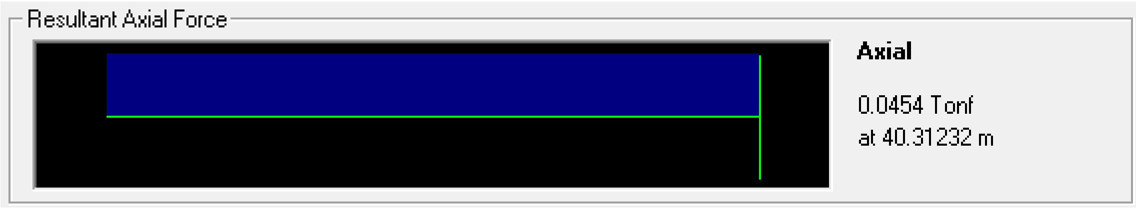


Figure 13. Axial force in cable 2 and in model 1 under wind force

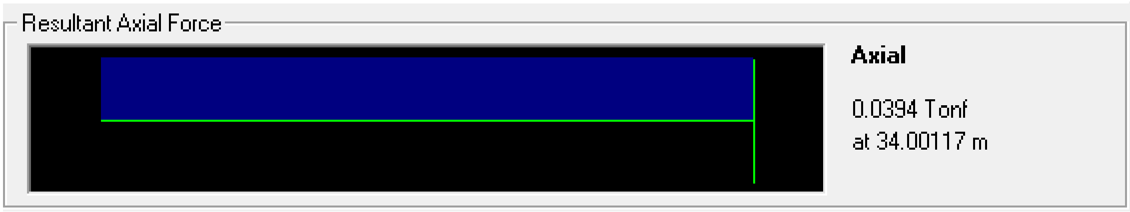


Figure 14. Axial force in cable 2 and in model 2 under wind force

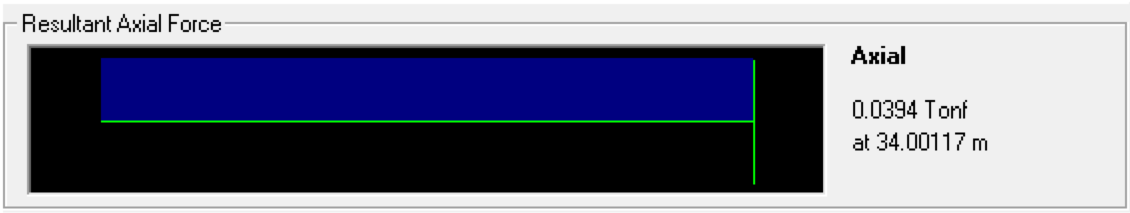


Figure 15. knot 17 dislocation in model 1 under wind load

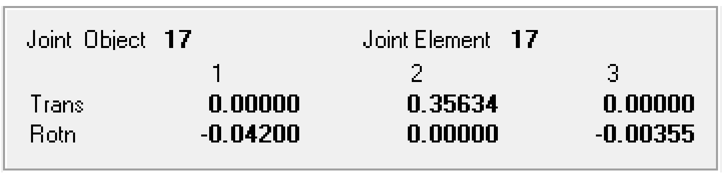


Figure 16. knot 17 dislocation in model 2 under wind load

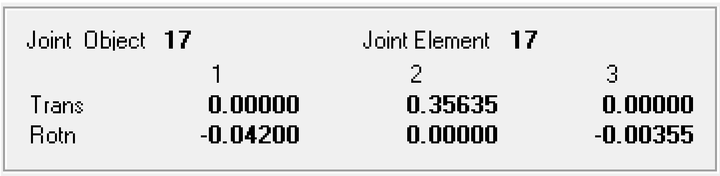


Figure 17. axial force in cable 1 and model 1 under earthquake static load

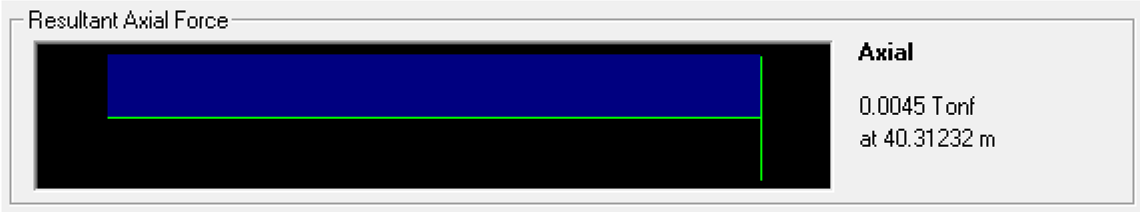


Figure 18. axial force in cable 1 and model 2 under earthquake static load

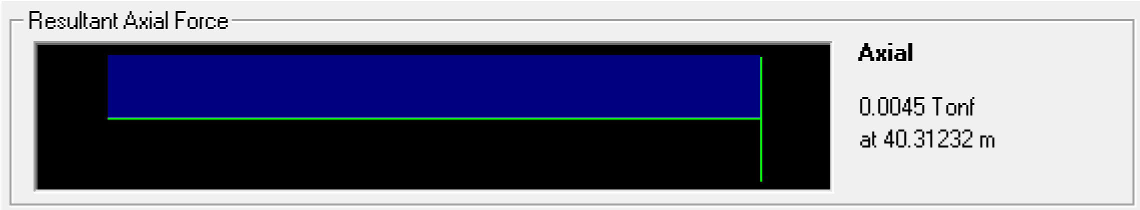


Figure 19. axial force in cable 2 and model 1 under earthquake static load

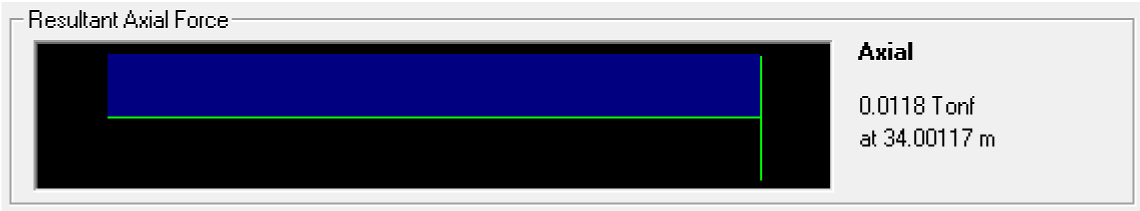


Figure 20. axial force in cable 2 and model 2 under earthquake static load

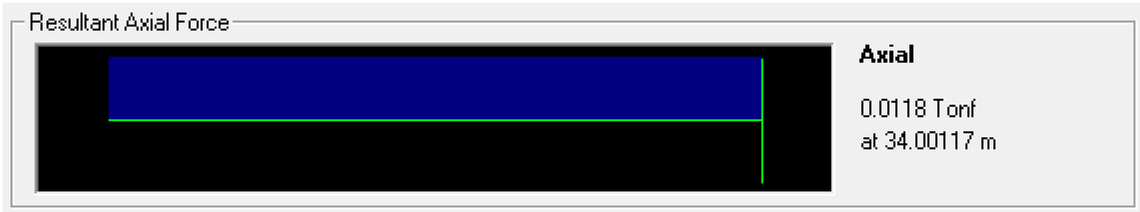
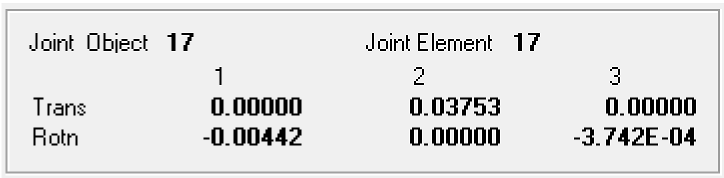


Figure 21. knot 17 dislocation in model 1 under earthquake static load



Joint Object **17** Joint Element **17**

	1	2	3
Trans	**0.00000**	**0.03753**	**0.00000**
Rotn	**-0.00442**	**0.00000**	**-3.742E-04**

Figure 22. knot 17 dislocation in model 2 under earthquake static load

Joint Object 17		Joint Element 17	
	1	2	3
Trans	0.00000	0.03754	0.00000
Rotn	-0.00442	0.00000	-3.742E-04

4-3-1 Models 3 and 4 under dead load

Figure 23. axial force in cable 1 and model 3 under dead load

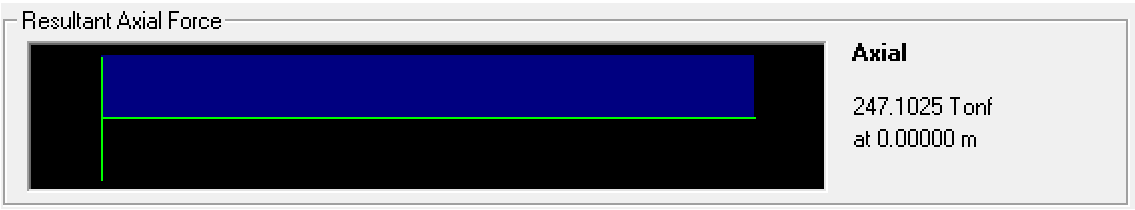


Figure 24. axial force in cable 1 and model 4 under dead load

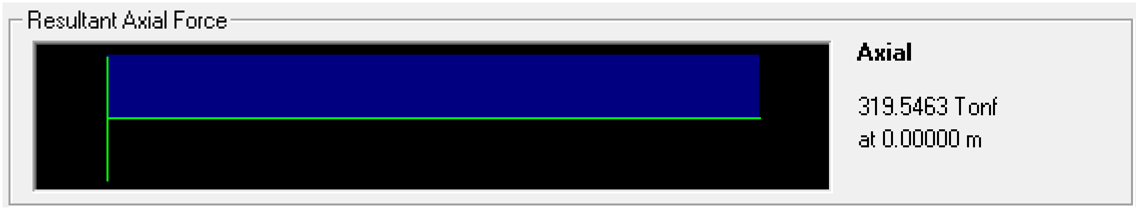


Figure 25. axial force in cable 2 and model 3 under dead load

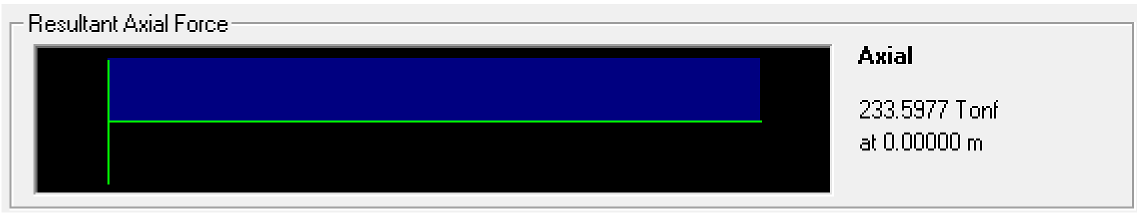


Figure 26. axial force in cable 2 and model 4 under dead load

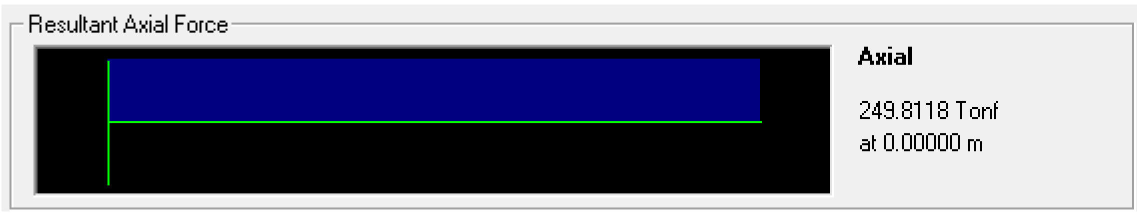
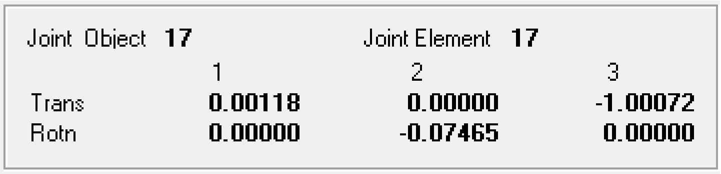


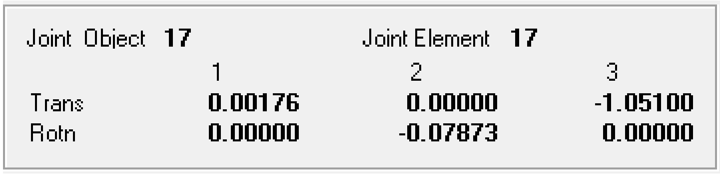
Figure 27. knot 17 dislocation in model 3 under dead load



Joint Object 17 Joint Element 17

	1	2	3
Trans	0.00118	0.00000	-1.00072
Rotn	0.00000	-0.07465	0.00000

Figure 28. knot 17 dislocation in model 4 under dead load



Joint Object 17 Joint Element 17

	1	2	3
Trans	0.00176	0.00000	-1.05100
Rotn	0.00000	-0.07873	0.00000

4-1-4 Models 3 and 4 under wind and earthquake load

Figure 29. axial force in cable 1 and model 3 under wind load

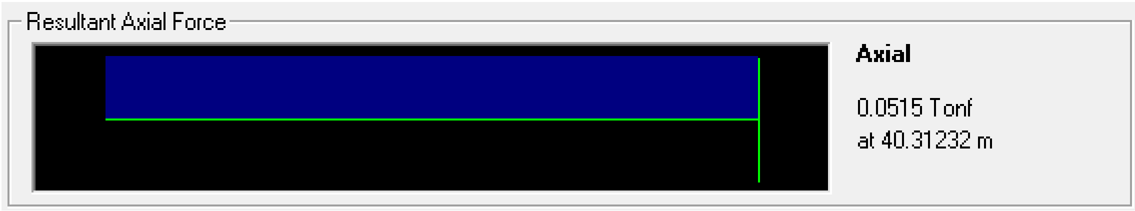


Figure 30. axial force in cable 1 and model 4 under wind load

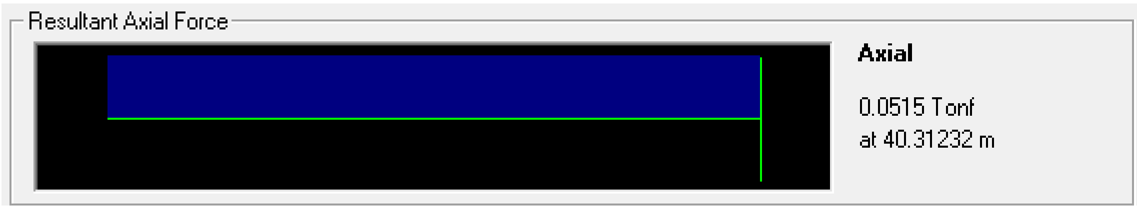


Figure 31. axial force in cable 2 and model 3 under wind load

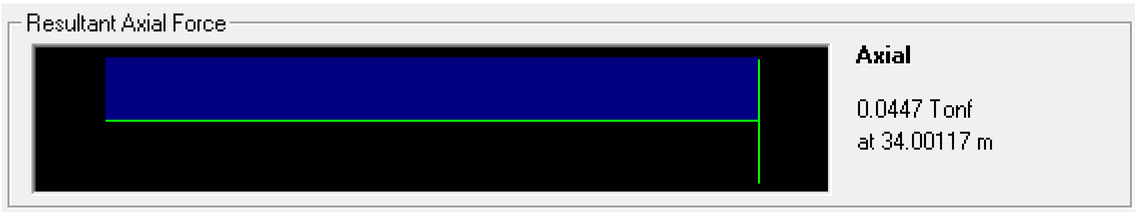


Figure 32. axial force in cable 2 and model 4 under wind load

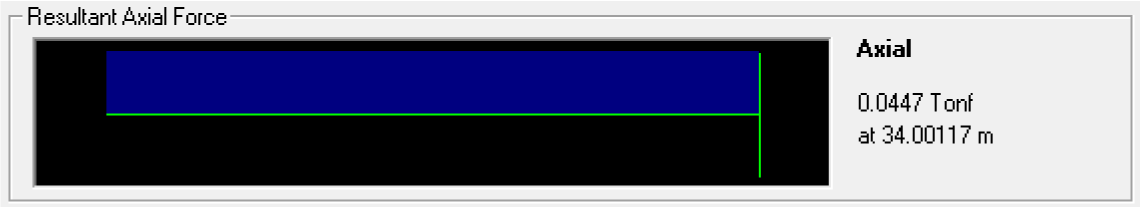
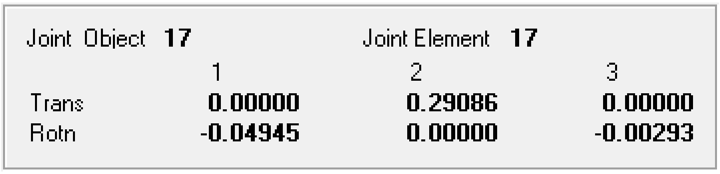


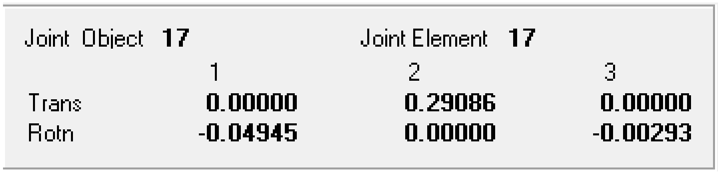
Figure 33. knot 17 dislocation in model 3 under wind load



Joint Object **17** Joint Element **17**

	1	2	3
Trans	**0.00000**	**0.29086**	**0.00000**
Rotn	**-0.04945**	**0.00000**	**-0.00293**

Figure 34. knot 17 dislocation in model 4 under wind load



Joint Object **17** Joint Element **17**

	1	2	3
Trans	**0.00000**	**0.29086**	**0.00000**
Rotn	**-0.04945**	**0.00000**	**-0.00293**

Figure 35. axial force in cable 1 and model 3 under earthquake static load

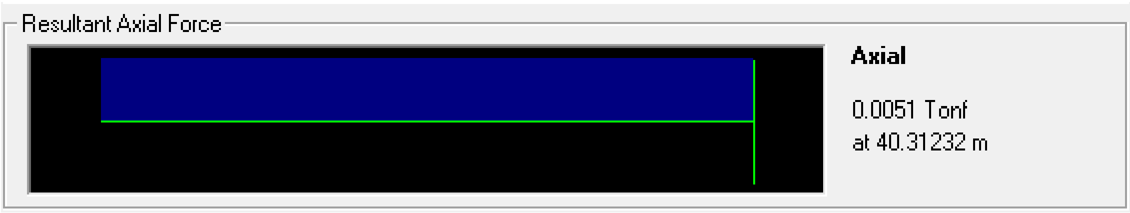


Figure 36. axial force in cable 1 and model 4 under earthquake static load

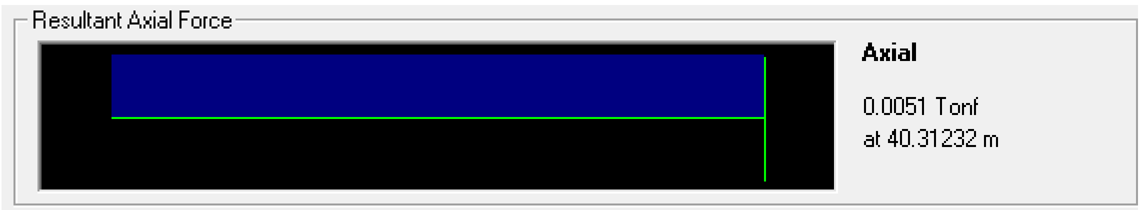


Figure 37. axial force in cable 2 and model 3 under earthquake static load

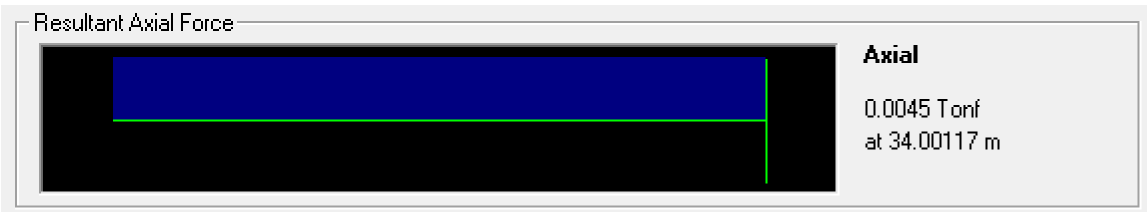


Figure 38. axial force in cable 2 and model 4 under earthquake static load

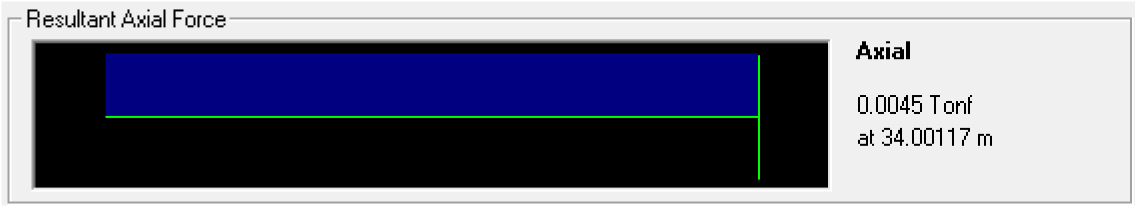
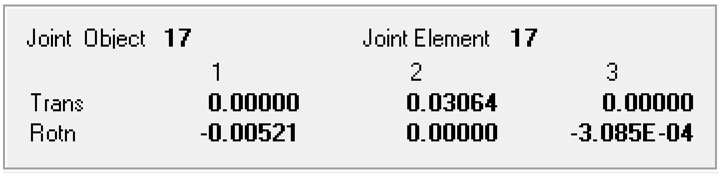
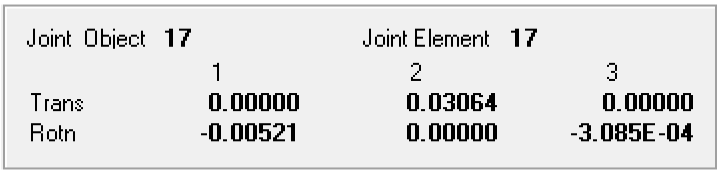


Figure 39. knot 17 dislocation in model 3 under earthquake static load



Joint Object 17		Joint Element 17	
	1	2	3
Trans	0.00000	0.03064	0.00000
Rotn	-0.00521	0.00000	-3.085E-04

Figure 40. knot 17 dislocation in model 4 under earthquake static load



Joint Object 17		Joint Element 17	
	1	2	3
Trans	0.00000	0.03064	0.00000
Rotn	-0.00521	0.00000	-3.085E-04

4-2 Dynamic spectral analysis

4-2-1 Models 1 and 2

Figure 41. axial force in cable 1 and model 1 under linear dynamic load

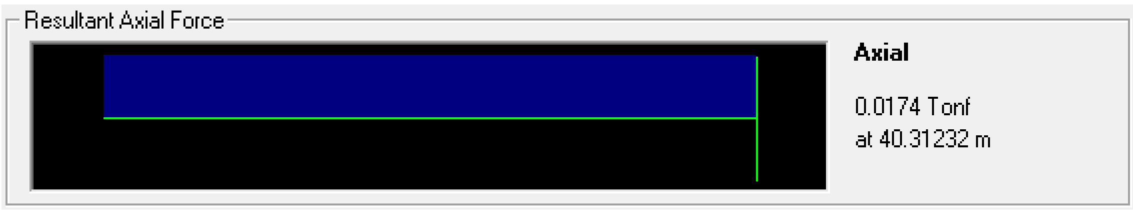


Figure 42. axial force in cable 1 and model 2 under linear dynamic load

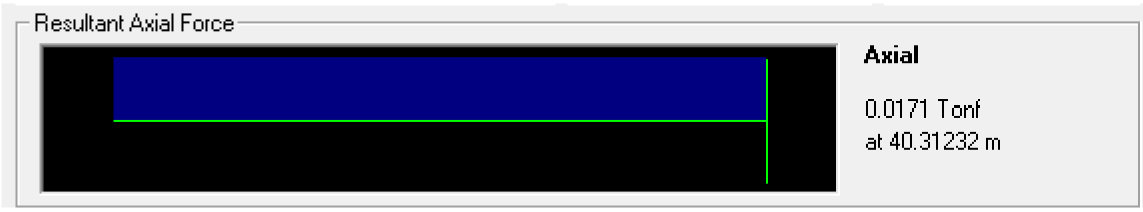


Figure 43. axial force in cable 2 and model 1 under linear dynamic load

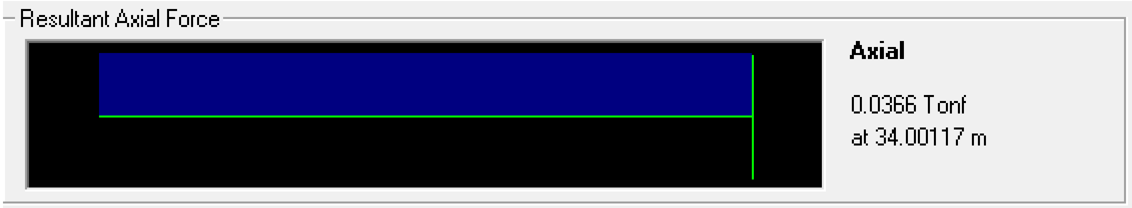


Figure 44. axial force in cable 2 and model 2 under linear dynamic load

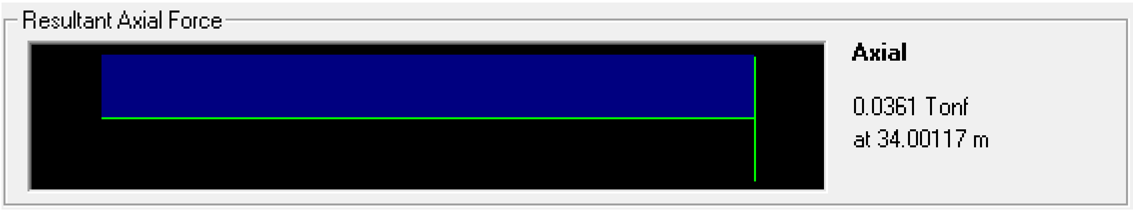


Figure 45. knot 17 dislocation in model 1 under linear dynamic load

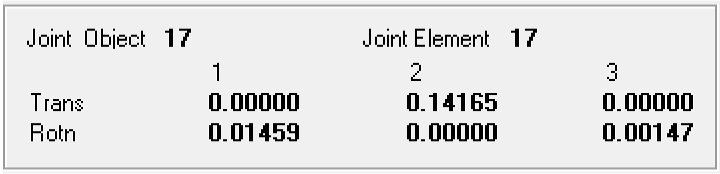
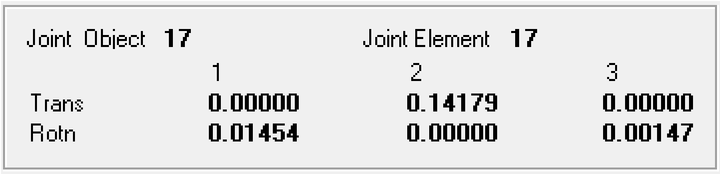


Figure 46. knot 17 dislocation in model 2 under linear dynamic load



4-2-2 Models 3 and 4

Figure 47. axial force in cable 1 and model 3 under linear dynamic load

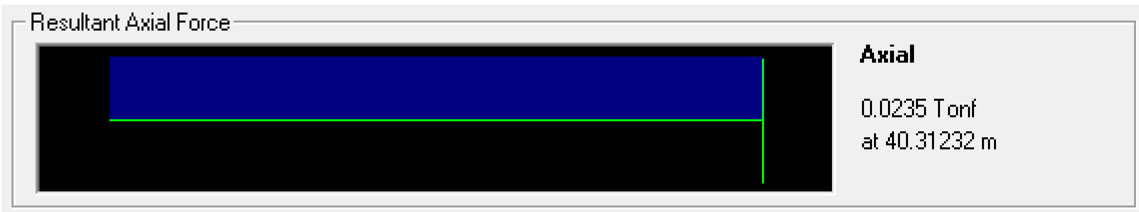


Figure 48. axial force in cable 1 and model 4 under linear dynamic load

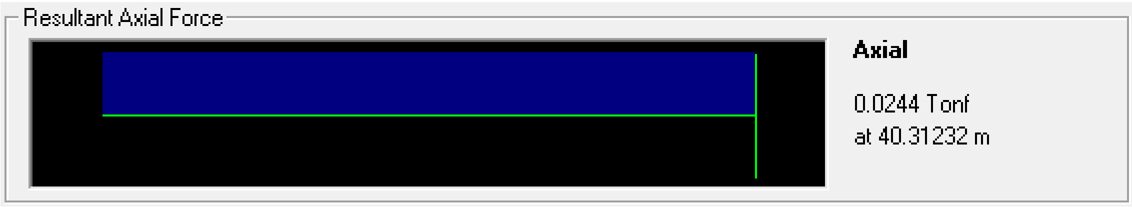


Figure 49. axial force in cable 2 and model 3 under linear dynamic load

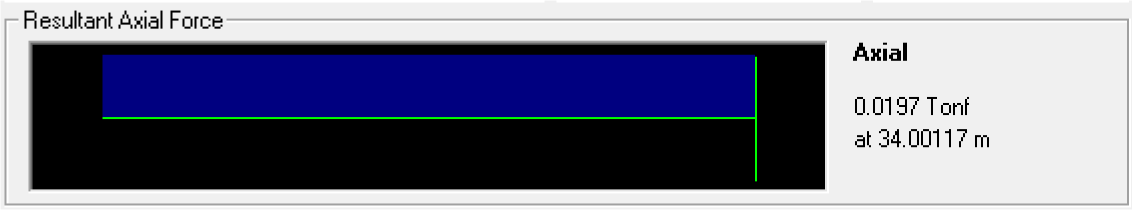


Figure 50. axial force in cable 2 and model 4 under linear dynamic load

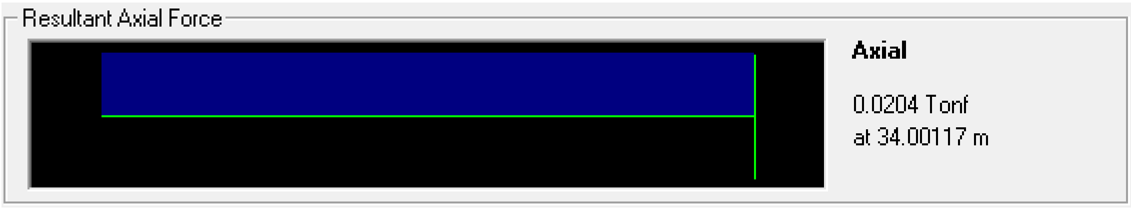


Figure 51. knot 17 dislocation in model 3 under linear dynamic load

Joint Object **17**		Joint Element **17**	
	1	2	3
Trans	**0.00000**	**0.10748**	**0.00000**
Rotn	**0.01721**	**0.00000**	**0.00114**

Figure 52. knot 17 dislocation in model 4 under linear dynamic load

Joint Object **17**		Joint Element **17**	
	1	2	3
Trans	**0.00000**	**0.10760**	**0.00000**
Rotn	**0.01721**	**0.00000**	**0.00114**

Dynamic spectral analysis also exercised horizontally to the structure, the results shows the forces and the dislocations of model 1, 2. Models 3 and 4 as well show that cable cutting has a little effect in this type of analysis. As everyone can see the results are consistent.

4-3 nonlinear static analysis (push over)

4-3-1 Models 1 and 2

In this type of analysis we investigate the results to force and dislocation. In the following we delineated the axial force in cables 1 and 2 also we presented model 2 push over curve.

Figure 53. member 1 axial force in model 1 under push 2

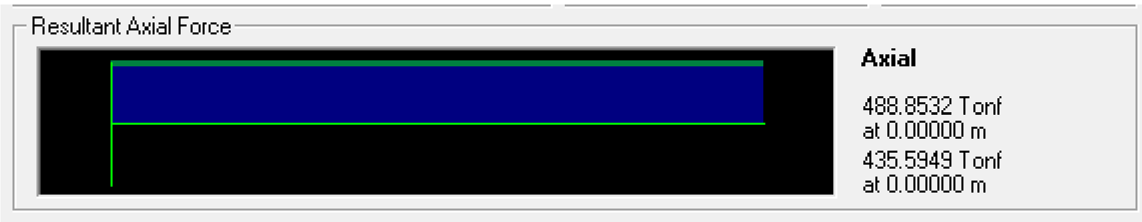


Figure 54. member 1 axial force in model 2 under push 2

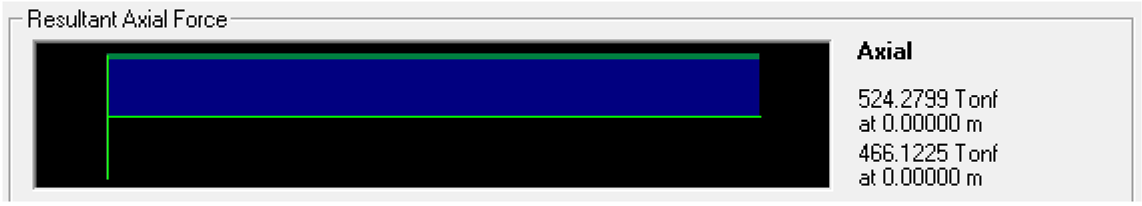


Figure 55. member 2 axial force in model 1 under push 2

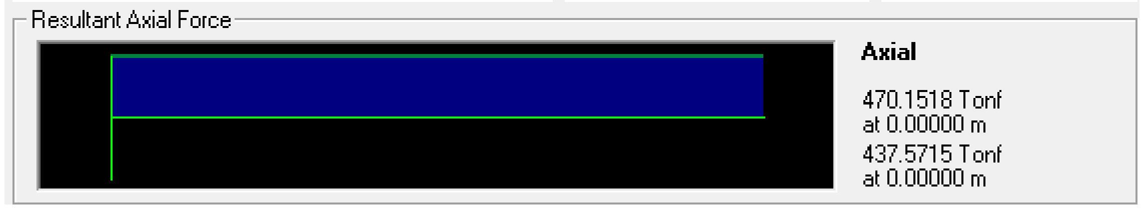
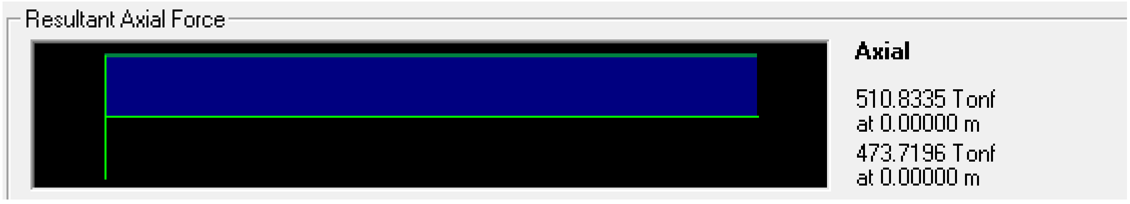


Figure 56. member 2 axial force in model 2 under push 2



4-3-2 Models 3 and 4

Figure 57. member 1 axial force in model 3 under push 2

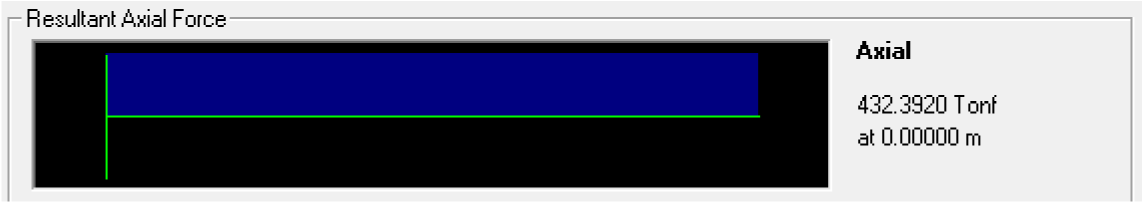


Figure 58. member 1 axial force in model 4 under push 2

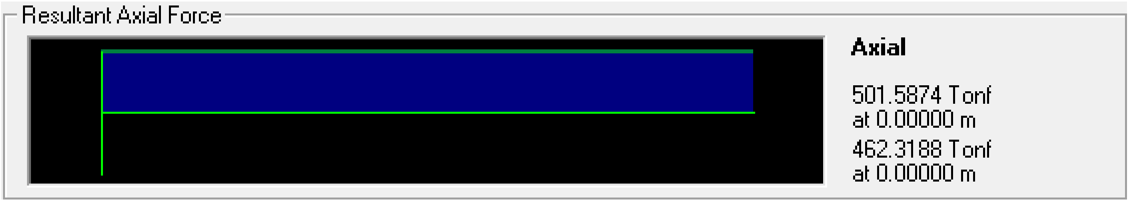


Figure 59. member 2 axial force in model 3 under push 2

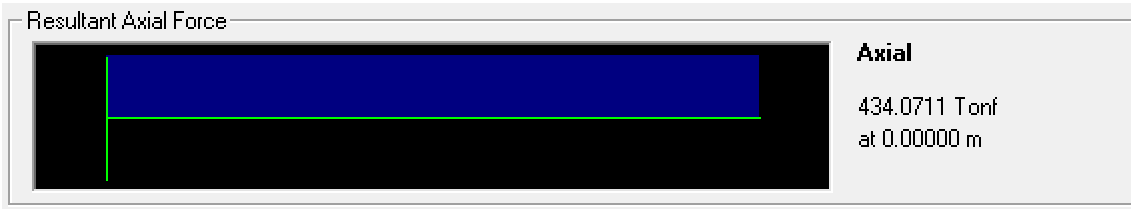
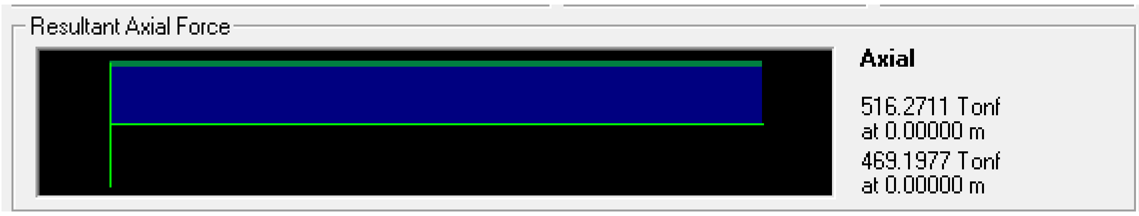
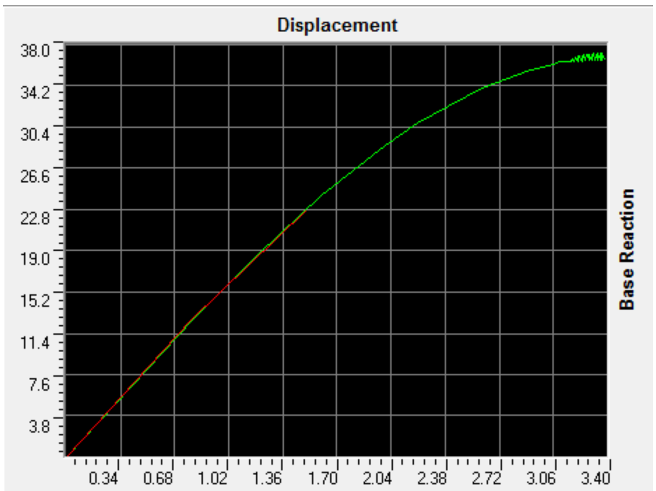


Figure 60. member 2 axial force in model 4 under push 2



Model 2 push over cure look likes figure below.

Figure 61. model 2 push curve



As we observe at the end of the curve structure became unstable and this means by cutting two cables the structure get destroyed gradually.

4-4 Nonlinear dynamic analysis

Investigating progressive collapse in cable stayed bridges is done by this analysis.

At first, in figure below we show nonlinear dynamic analysis of cables 1 and 2 forces by one of the accelerogrphs for models 1 and 4. We also present knot 17 dislocation with this accelerograph and study a condition in which two cables break and so we study other cables force changes.

Figure 62. axial force- time curve in cable 1 and model 1 by accelerograph L

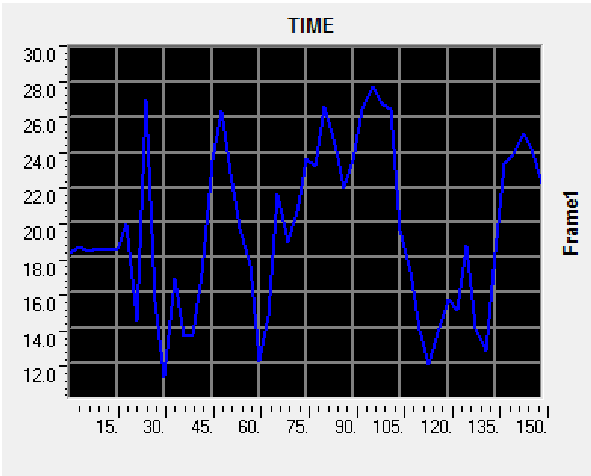


Figure 63. axial force- time curve in cable 1 and model 4 by accelerograph L

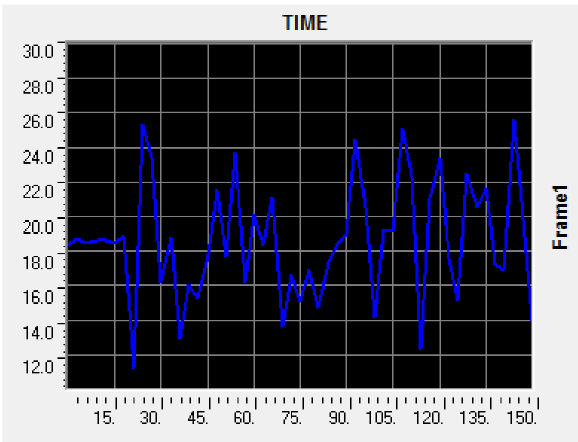


Figure 64. axial force- time curve in cable 2 and model 1 by accelerograph L

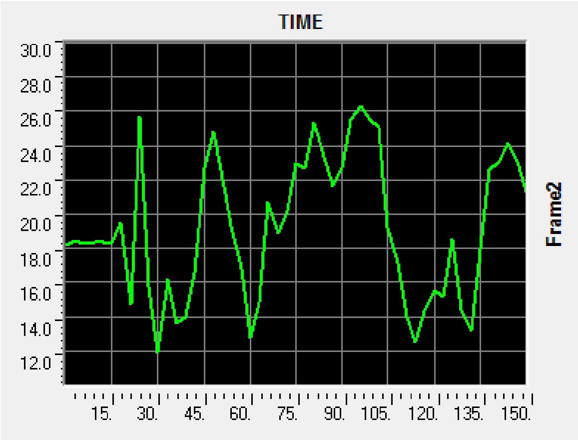


Figure 65. axial force- time curve in cable 2 and model 4 by accelerograph L

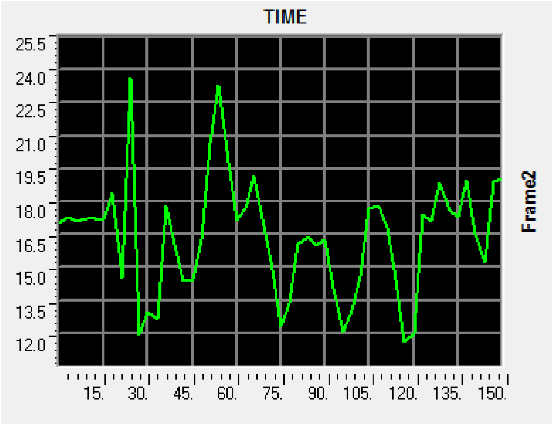


Figure 66. dislocation-time curve for knot 17 in model 1 by accelerograph L

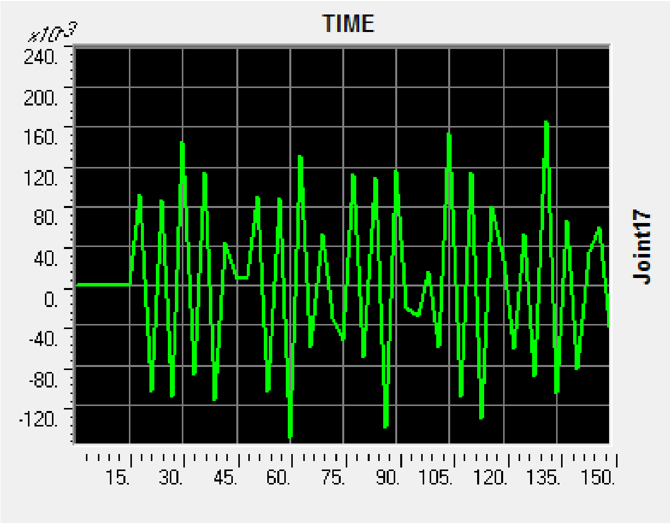
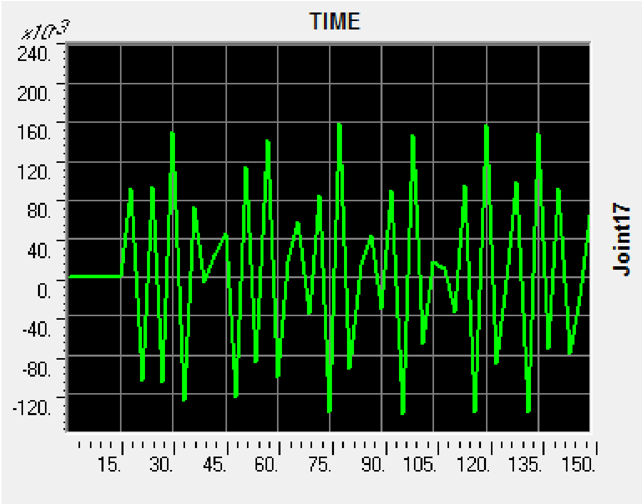


Figure 67. dislocation-time curve for knot 17 in model 4 by accelerograph L



We can observe progressive collapse in figures below. In diagrams below at first we exercise all cables forces when the structure is under accelerograph L. in this situation none of the cables are broken. As the time passes two cables become to break threshold and so make some changes in rest of the cables. When these two cables are broken for a few seconds (as you can see in diagram) all cables tolerated higher force and in short time we observe a huge fall in the cables forces. Here we see that after two cables are broken at first cable 7 then cables 11, 12, … break and the structure gets unstable and slowly rest of the cables get to break limit and the bridge structure inclines to progressive collapse.

Figure 68. cables' axial force in model 2 when two cables get close to their breaking points

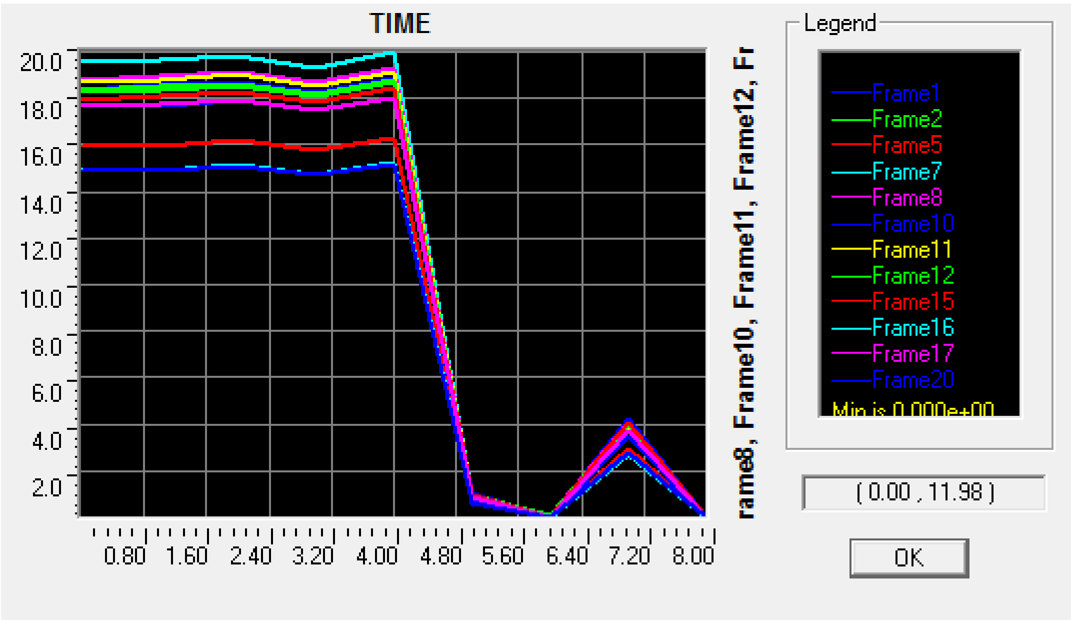


Figure 69. cables' axial force in model 4 when two cables get close to their breaking points

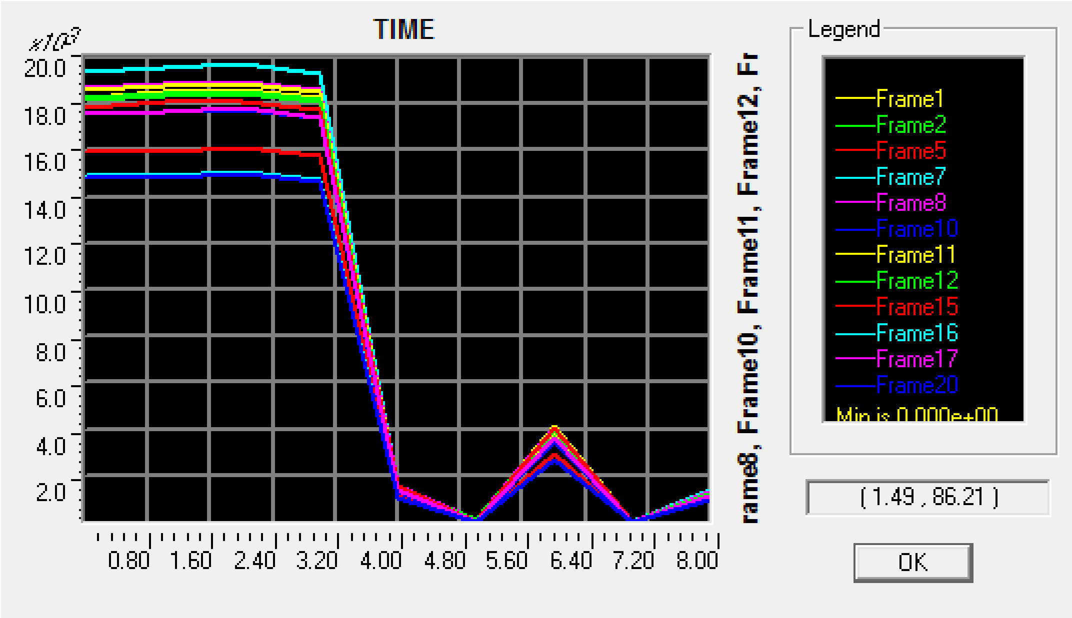


Figure 70. knot 17 dislocation diagram in model 2 when two cables get close to their breaking points

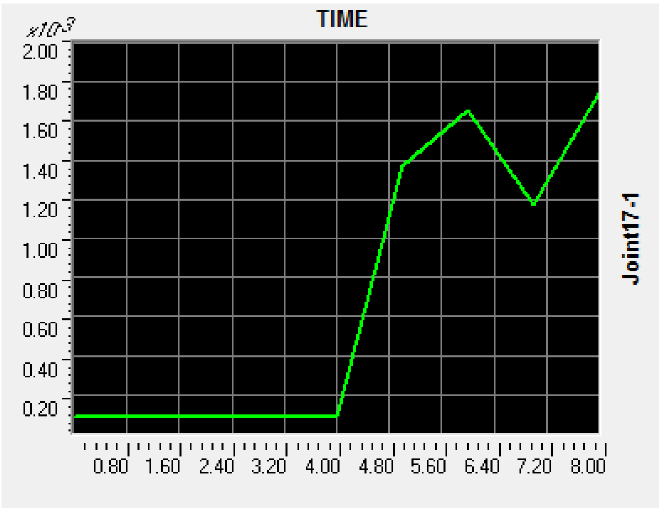
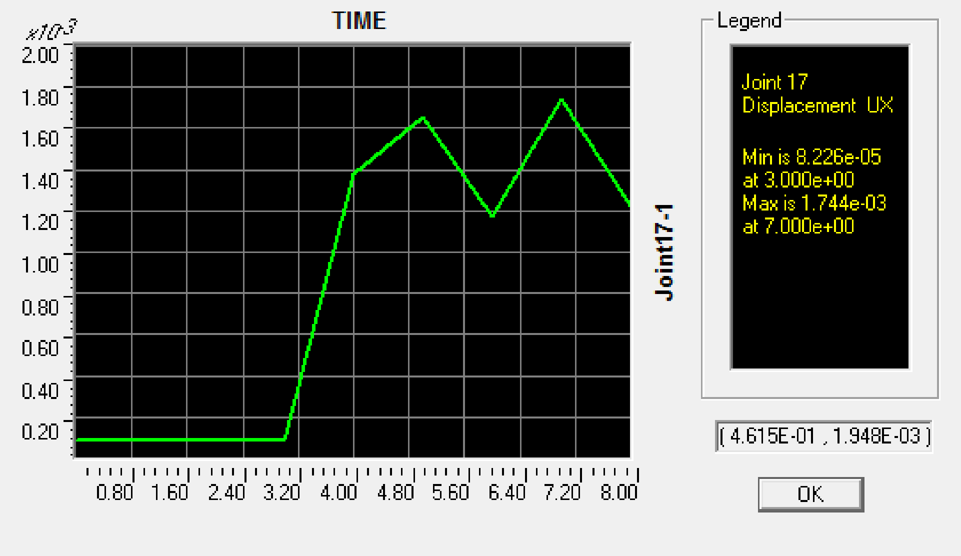


Figure 71. knot 17 dislocation diagram in model 4 when two cables get close to their breaking points



Using the diagram we observe that this knot dislocation was constant at the beginning and when two cables break huge dislocations happens.

5- Conclusion

First and the second models have pylon with a 20 m height of lower deck. The difference is that in the second model two cables got to their break threshold. In the third and fourth model we decreased thee pylon height to its half. In this section we categorize the results of tensions and dislocations.

In an equal static analysis we proceeded to study the results obtained from dead, wind and earthquake loads.

By studying models 1 and 2 under dead load we concluded that when two cables destroy force distribution happens and forces in other cables increase. This increase can be up to 1.5 more than what they were designed for. This leads to cable destruction and finally the structure destroy. In the end the possibility that the structure runs down because of gravity loads heading toward progressive collapse is low. Dislocation is increased in model 2. The same results came out for models 3 and 4. This means that by reducing the pylon's height even to its half no big changes happen in progressive collapse. We also observed that cables' forces in model 3 have increased a little in relation to model 1. For study the dislocation we watched nod 17 dislocation. This knot's dislocation in model 2 is more than model 1. Model 4 dislocation was also more than model 3 and when the cables tear apart, dislocation increases as well. When we compare dislocation is model 1 and 3 we perceive that dislocation decreases by reducing the height.

Under wind and earthquake static load we found out that the forces and dislocations have not been changed significantly in comparing models 1 and 2 and models 3 and 4. Forces also increased in model 3 in relation to model 1. Dislocations also had a small change.

In nonlinear static analysis we observed that model 2 forces in relation to model 1 also model 4 in relation to model 3 increased a little.

We represented axial force alterations of the cables versus time by non-linear dynamic analysis. We observed in diagrams that initially when the structure is placed under accelerograph L, forces of all the cables are entered constantly. In this situation, no cable is torn apart. As time passes, two cables exceed the breakage threshold and cause changes in other cables. When these two cables are torn apart, forces of other cables reach to an extent more than the previous one, and then in a short period we will observe severe subsidence of cables' forces. It was also observed that after the breakage of two cables, first cable 7 and then cable 11 and 12 torn apart (due to the relatively large axial force compared to other cables) and the structure proceeds to instability. Other cables gradually reach the breakage threshold and the structure inclines to the progressive collapse.

About the shift, it can be said that initially, shift in the knot 17 has been constant and when two cables are torn apart significant shift in the knot 17 is observed.

In comparison of models 2 and 4, the structure stiffness is increased because of the pylon altitude is halved in model 4 therefore the structure behavior inclines to less flexibility. This fact leads the structure to face progressive collapse sooner. As it is shown in the diagram, in model 4, cable forces have reached to zero earlier. Also, model 4 has reached to breakage with smaller shift.

As it is obvious in figure 70, there exist more shifts of different points in the bridge in model 3 in comparison to model 1. By observing figure 71, it is obvious that this shift has become more in model 4 in comparison to model 3.

Figure 72. dislocation of different points on bridge in models 1 and 3

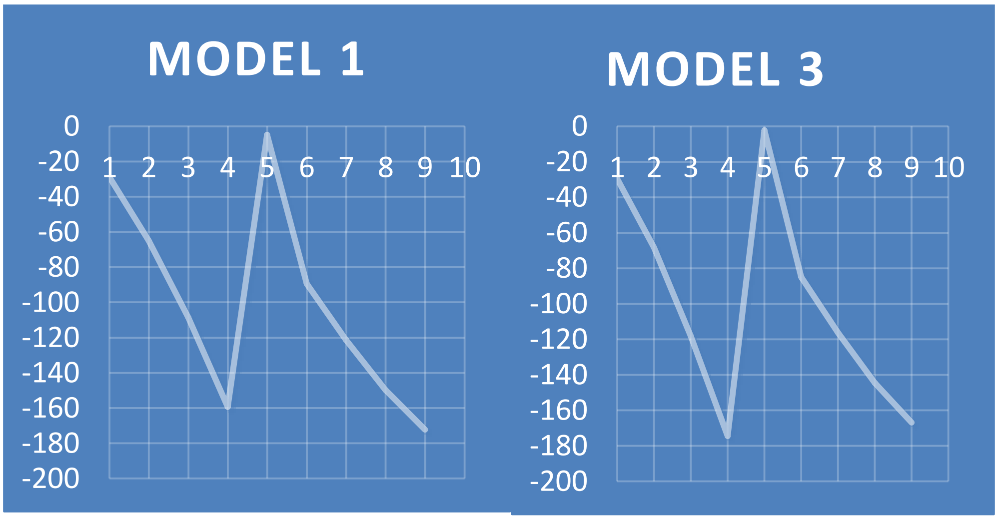
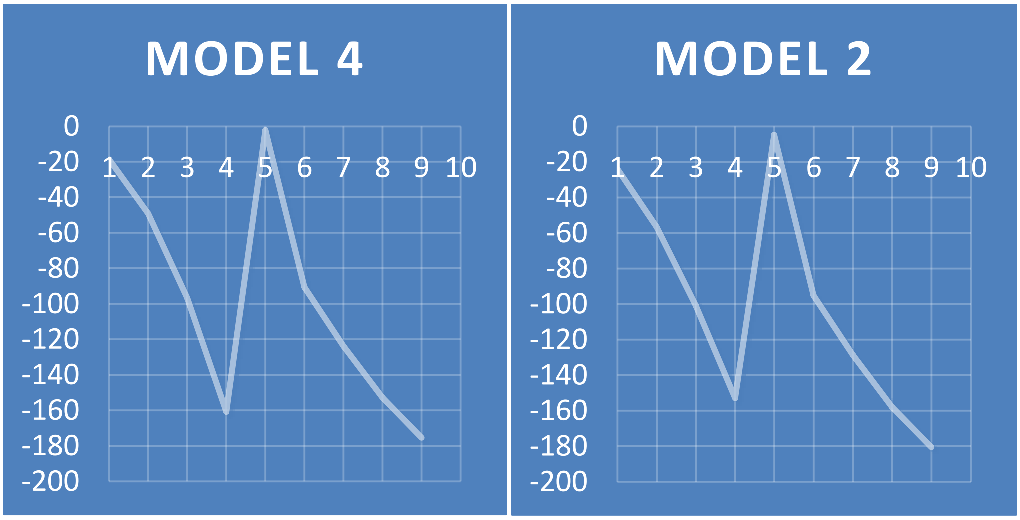


Figure 73. dislocation of different points on bridge in models 2 and 4



Figures 74 and 75 also demonstrated established forced in different elements of 4 types of bridge models. As it is obvious because of hardness increase in model 4, absorbed force in the elements of this model is raised while other models have less absorbed force.

Figure 74. established force in different elements of the bridge in models 1 and 3

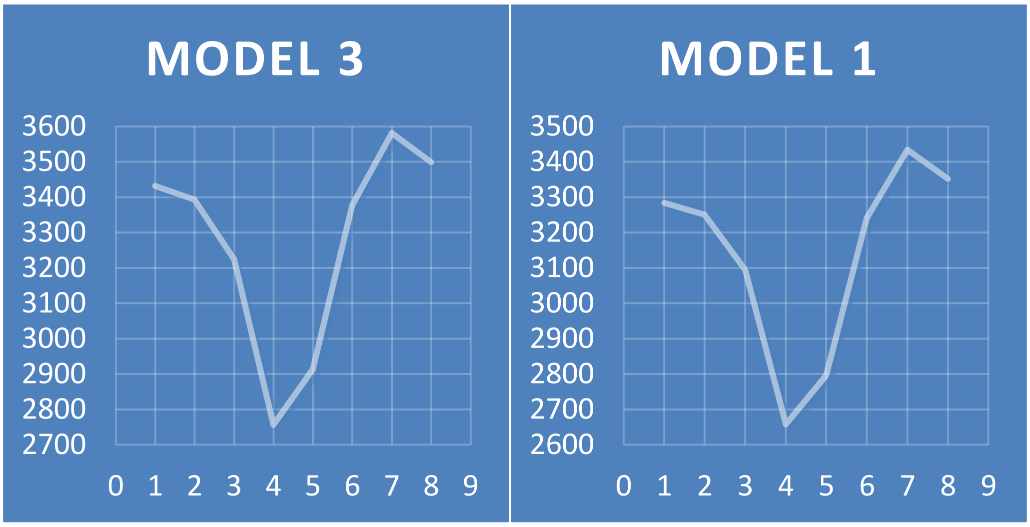
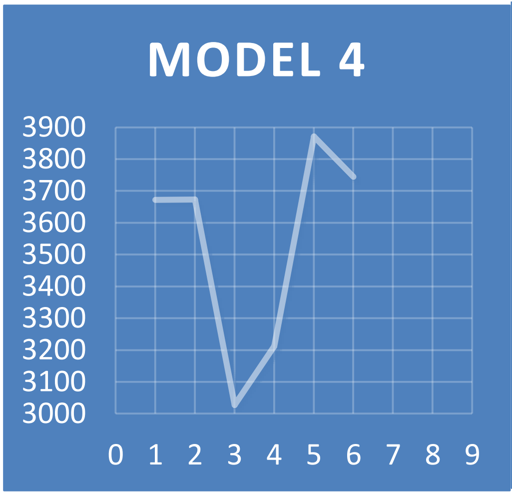
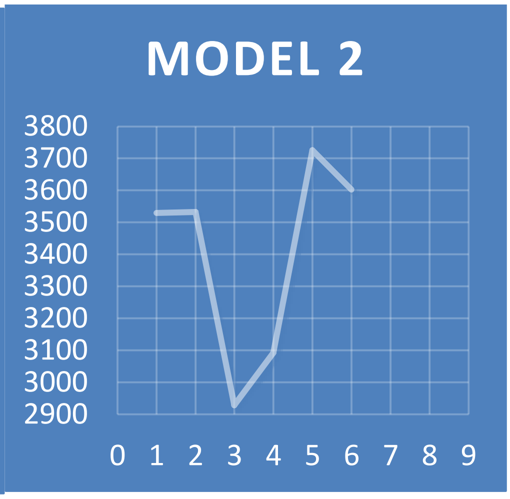


Figure 75. established force in different elements of the bridge in models 2 and 4





Finally we compared dislocations of different points of 4 samples and study the established forces in the elements of the models. It is shown in figure 76 and 77.

Figure 76. established forces in different elements in model 2 and 4

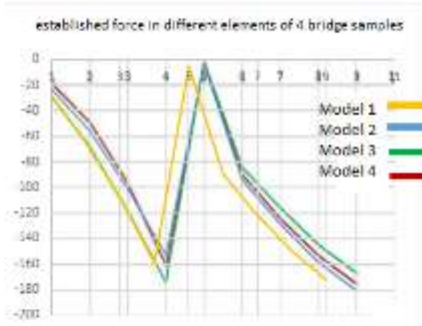
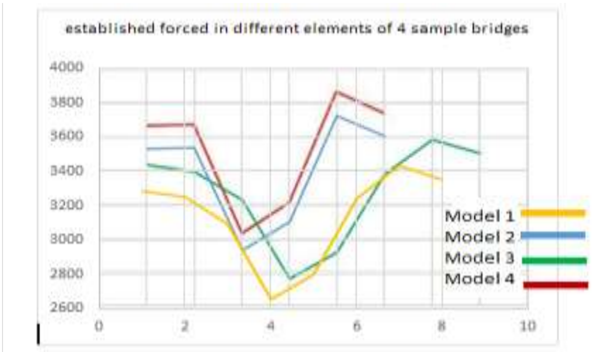


Figure 77. established forces in different elements in model 2 and 4



References

[1] Darian, Amir Saedi, et al 2012, "progressive collapse theory and application", Darian engineering publication, Tehran.

[2] Fliming, J. F. and Egeseli, E. A., 1980, "Dynamic behavior of a cable-stayed bridge", Earthquake Engineering and Structural Dynamics, Vol. 8, No. 1, pp. 1-16.

[3] Fliming, J. F., 1979, “Nonlinear static analysis of cable-stayed bridge structures”, Computers and Structures, Vol. 10, pp. 621-635.

[4] Abdle-Ghaffar and A. M., Nazmy, A. S, 1991, “3-D nonlinear seismic behavior of cable-stayed bridges”, ASCE, Journal of Structural Engineering, Vol. 117, No. 11, pp. 3456-3476.

[5] Abdle-Ghaffar, A. M. and Khalifa, M. A, 1992, “Importance of cable vibration in dynamic of cable-stayed bridges”, ASCE, Journal of the Engineering Mechanics, Vol. 117, No. 6, pp.

[6] Nazmy, A. S. and Abdle-Ghaffar, A. M., 1992, “Effect of ground motion spatial variability on the response of cable-stayed bridges”, Earthquake Engineering and Structural Dynamics, Vol. 21, pp. 1-20.

[7] Nazmy, A. S. and Abdle-Ghaffar, A. M., 1990 “Non-linear earthquake-response long-span cable-stayed bridges: Applications”, analysis of Earthquake Engineering and Structural

[8] Soneji, B.B. and Jangid, R.S., 2007, “Passive hybrid systems for earthquake protection of cable-stayed bridge”, Engineering Structures, Vol. 29, pp. 57–70..

[9] Soneji, B.B. and Jangid, R.S., 2008, “Influence of soil–structure interaction on the response of seismically isolated cable-stayed bridge”, Soil Dynamics and Earthquake Engineering, Vol.28, pp. 245–257.

[10] Ali, H. M. and Abdle-Ghaffar, A. M, 1995, “Modeling of rubber and lead passive-control bearings for seismic analysis”, ASCE, Journal of Structural Engineering, Vol. 121, No. 7, pp. 1134-1144.

[11] Takahashi, Q. Wu., Nakamura, K. S., 2003, “The effect of cable loosening on seismic response of a prestressed concrete cable-stayed bridge”, Journal of Sound and Vibration Vol. 268, pp. 71–84.

[12] Cao Gao Jiang et al. 2012, Various static and dynamic analysis process in the progressive erosion of the cable stayed bridge. Engineering Structures.

[13] Yan, D., Chang, C.C., 2010. Vulnerability assessment of single-pylon cable-stayed bridges using plastic limit analysis. Engineering Structures, 32(8):2049-2056 [doi:10.1016/j.engstruct.2010.03.005]

[14] Wolff, M., Starossek, U., 2008. Robustnsess Assessment of a Cable Stayed Bridge. Proceeding of the International Conference on Bridge Maintenance, Safety and Management, Seoul, Korea.

[15] Zoli, T.P., Steinhouse, J., 2007. Some Considerations in the design of Long Span bridges against Progressive collapse, available from:

http://www.pwri.go.jp/eng/ujnr/tc/g/pdf/23/23-2-3zoli.pdf [Accessed on June 30, 2010].

[16] Koshtegar, B. Miri, M. 2012. A parametrical study on seismic nonlinear behavior of large span static cable bridge with box deck, Iranian society of steel, Tehran.