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Study of the collapse of Sardabroud-Chalous truss bridge

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Abstract

Many of the old bridges in northern Iran, which are often more than 50 years old, are made of steel trusses. The superstructure of these bridges usually consists of two simple and parallel trusses that increase lateral stability, the upper part of these two trusses are connected using bracing elements. In some truss bridges such as the Sardabroud-Chalous bridge, the transverse brace has been removed due to the small length of the span (about 31 meters). These types of trusses that do not have transverse restraints in the upper part are called pony trusses, which have less lateral resistance due to the removal of transverse restraints. On December 25, 2009, while the trailer was passing, a steel cargo weighing about 10 tons was released from the trailer floor and thrown towards one of the vertical elements of the truss. The impact of this heavy object causes the failure of this member and the subsequent failure of the adjacent members, which eventually leads to the collapse of the entire structure. In this paper, the progressive failure mechanism of Sardabrood Bridge will be studied using ABAQUS software. The results of sensitivity analysis and Downstream analysis show that except for zero force elements, other vertical and oblique elements have significant sensitivity that should be prevented from being damaged. Interestingly, at the moment of failure and after the failure, the alternative route is the force distribution, which is mainly the forces trying to cross the pressure rim, but small deformations in a chain led to large deformations and caused the progressive failure, which destroyed the bridge in 0.7 seconds. (DOI:**https//doi.org/10.52547/JCER.4.2.46**)

Keywords: Steel bridges, Truss, Progressive failure, Sensitivity analysis

1. Introduction

Many of the old bridges in northern Iran, which are often more than 50 years old, are made of steel trusses. The superstructure of these bridges usually consists of two simple and parallel trusses that to increase lateral stability, the upper part of these two trusses are connected using bracing elements. In some truss bridges such as the Sardabroud-Chalous bridge, due to the small length of the span (about 31 meters), the transverse brace has been removed (Figure (1)). These types of trusses that do not have transverse restraints in the upper part are called pony trusses, which have less lateral resistance due to the

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removal of transverse restraints. On December 25, 2009, while the trailer was passing, a steel cargo weighing about 10 tons was released from the trailer floor and thrown towards one of the vertical elements of the truss. The impact of this heavy object causes the failure of this member and the subsequent failure of the adjacent members, which eventually leads to the collapse of the entire structure.

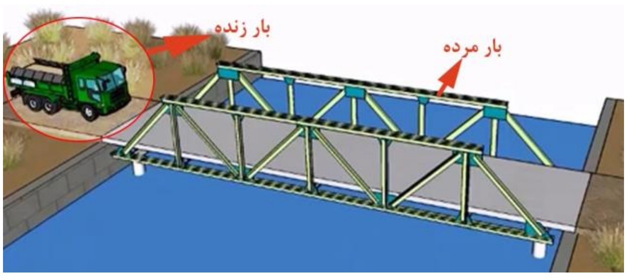


Fig. 1. Schematic view of Sardabroud Bridge

Since some coastal road bridges in Gilan, Mazandaran, and Golestan provinces with a similar structural system are still under traffic load, so the study of this type of failure, which is called progressive failure, is of considerable importance.

Progressive failure can be defined as the spread of an initial local rupture from one member to another, which ultimately leads to the failure of the entire structure or disproportionately much of it. This improper failure is due to the small initial failure caused by unforeseen events and indicates that the structural system is not able to withstand the propagation of failure due to insufficient bearing capacity

Most truss stairs are classified as critical failure structures whose serious problem is their high vulnerability to progressive failure. Progressive failure of truss stairs can begin with rupture (tensile failure) or bending (compressive failure) of truss members. Existing standards point to three ways to reduce progressive failure. The first method is based on reducing exposure to injuries and damages. The other two methods are indirect methods and direct methods [1 and 2]. In the indirect method, failure resistance is provided by creating continuity, ductility, and increasing resistance by creating higher indefinite degrees in the structure. In the indirect method, progressive failure resistance is provided by increasing the resistance of key structural members to specific loads or by bridging across the local failure area. The alternative load transfer method is one of the methods to investigate the progressive failure in which the critical member is removed and the structure is designed so that in case of destruction of this member, alternative routes for transfer of load from that member and bearing members around this member Without total collapse, have additional capacity to withstand its force [1 and 2].

Liu [3] examined common European and American code design methods to prevent progressive failure due to abnormal loading. Joakim and Tavan Kim [4] investigated the progressive breakdown resistance in steel bending frames using possible alternative welding. Lou et al. [5] investigated the evaluation of frame stability index against progressive failure using push-up analysis. Weibo et al. [6] stated that the design goal in the local failure of structures that are mostly under gravity and explosive loads is focused on increasing indeterminacy and stability index to prevent local failure. In their research, they examined bridges damaged in previous earthquakes and concluded that retrofitting can increase the performance and safety of existing bridges, provided that the damage extends from the initial failure to the final sale and the effects of the structural failure mechanism. Be well considered

In this research, the performance of the Sardabroud truss bridge against impact load will be evaluated and the sensitivity of elements exposed to impact load will be studied using push-up analysis. The results show that due to the high sensitivity of the elements that are subject to impact, except for zero force elements, for other oblique and vertical elements, their damage should be properly prevented in order to prevent progressive failure The bridge structure should be prevented.

2. Research method

In this paper, to determine the critical member of one of the types of truss bridges, which is called Pony Truss due to lack of bracing, the progressive failure of Sardabroud truss bridge, which has suffered a total collapse as a result of damage to one of the vertical border elements on December 25, 2009. (Figure (2)), will be studied.

This steel bridge consists of two parallel trusses with a span of 30 meters and a height of 5 meters, the geometry, and characteristics of its sections are shown in Figures (3) and (4).

Fig. 2. the collapse of Sardabroud bridge due to heavy load collision with a key element of the structure

In this paper, to study the progressive failure of the Sardabroud Bridge, the steel truss in Abacus software is modeled in two dimensions using the Beam element.

According to the information received from the Housing and Urban Development Department of Chalous city, the total weight of the bridge is about 225 tons. Therefore, the dead load entering the middle and side nodes of the truss is about 184 and 92 kN, respectively. The live load has been applied on the bridge structure, assuming a 40-ton truck passes.

2.1. Validation

To evaluate the correctness of the modeling done in the software, the amount of vertical displacement of the middle node due to the 40-ton load in this node has been calculated in both numerical and analytical ways. The results extracted from the Abacus software show that the vertical displacement of the middle node is close to 1 cm (Figure (5)).

On the other hand, using the unit load method (Equation (1)), the vertical displacement of the middle truss knot due to the presence of 40-ton load in this knot is equal to 0.78 cm.

$$1 \times \Delta = \sum \frac{nNl}{EA} \qquad (1)$$

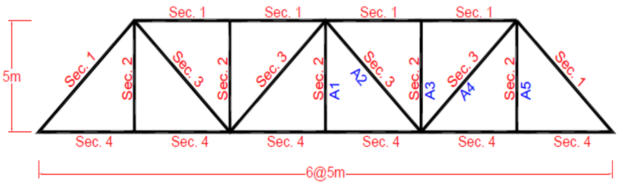


Fig. 3. Geometry of Sardabroud bridge truss

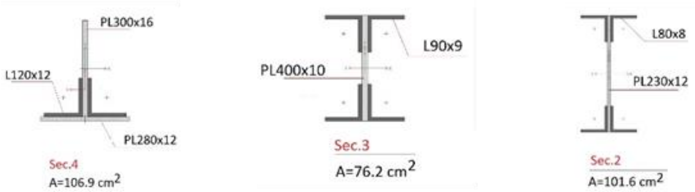


Fig. 4. Sardabroud truss bridge sections

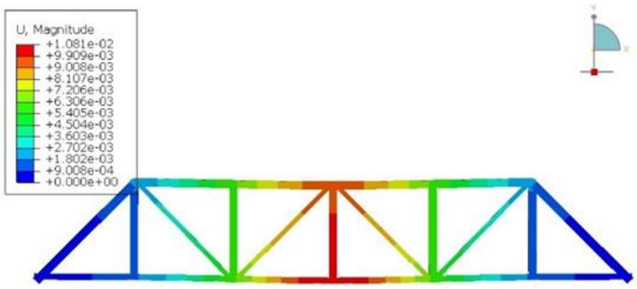


Fig. 5. Contours related to the vertical deformation of the model, during the application of a load of 40 tons to the center of the bridge.

In this regard:

Δ Obtained deformation of the center of the bridge

n The internal force created in each member, due to the application of a unit load of one ton applied at the center of the bridge

N internal force created in each member, due to the application of 40 ton load applied in the center of the bridge

L The length of each member

E modulus of elasticity of steel

A area of each member

As can be seen, the analytical and numerical results are about 20% different from each other, which can be considered appropriate due to the nonlinear effects in numerical modeling and the simplifying assumptions included in the analytical calculations.

2.2. Sensitivity analysis

Sensitivity analysis is used to determine the key element in progressive failure. This analysis is calculated based on the total capacity of the structure before and after the removal of the key element. The sensitivity index is defined using Equation (2) [7]:

$$SI = (\lambda 0 - \lambda_{damage}) / \lambda 0 \qquad (2)$$

In this regard, λ0 is the total load capacity before removing the key element and λdamage is the load capacity after removing the key element. The range of sensitivity index is between zero and one that the higher the sensitivity index for an element (close to one), the lower the load-bearing capacity of the structure if that member is removed; Therefore, the element with the highest sensitivity index will be the key element of the structure.

3. Investigation of Sardabroud bridge

3.1. Sensitivity of Sardabroud bridge truss elements

Due to the field visit, the load of the truck with the bridge truss is limited to vertical and oblique elements. On the other hand, according to the symmetry in the bridge structure, the sensitivity index of the five main elements shown in Figure (3) is investigated.

To calculate the capacity of the structure, the lower end node of the removed element is gradually shifted in the vertical direction. Diagram of changes The sum of the support reaction against the vertical displacement of the end node is extracted as the capacity diagram. The maximum amount of force in the capacity diagram is considered as the load-bearing capacity of the structure; An example of a structural capacity diagram after targeting the main element A1 in Figure (3).

it has been shown; According to this figure, the capacity of the structure after the removal of A1 is equal to 1490 kN. After calculating the capacity of the structure, the sensitivity index of the main elements was calculated using Equation (2), the results of which are presented in Table (1).

As can be seen, the sensitivity index for the removal of element A3 is 0.02, which is very small; Of course, this is not far-fetched given the zero-force of this member. On the other hand, according to the sensitivity table, the adjacent elements are more than the middle elements of the bridge.

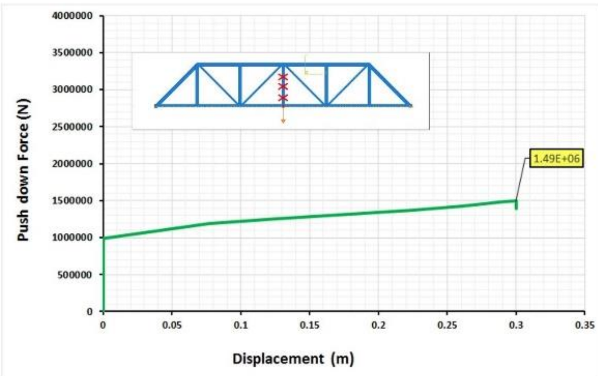


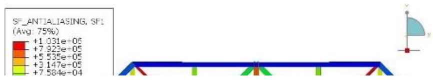
Fig. 6. Capacity diagram of Sardabroud bridge truss after removing element A1

Table 1

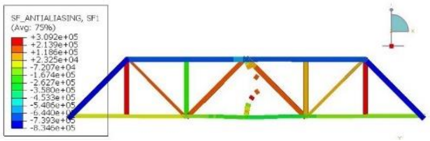
Sensitivity index of truss elements that are likely to be damaged when passing the truck

3.2. Progressive failure in Sardabroud bridge

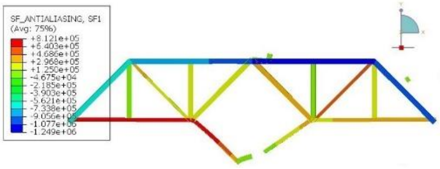
Based on the intermediate inspection and available documents, it can be said that the heavy load of the truck hit the middle element of the truss (column A1)



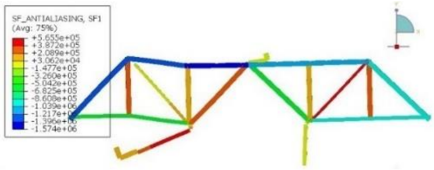
A: Time 2.8 seconds



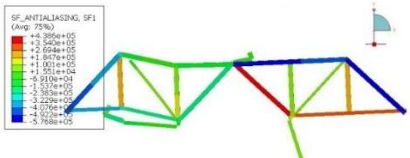
B: In time 2.89 seconds



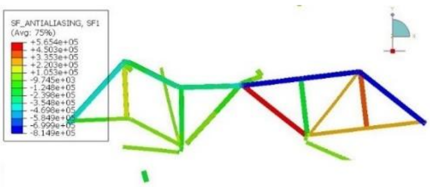
C: In 2.94 seconds



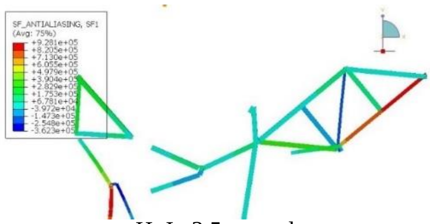
D: In 2.98 seconds



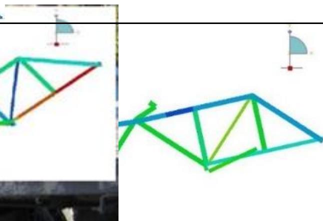
E: In 3.03 seconds



f: in 3.12 seconds



H: In 3.5 seconds



G: In 3.21 seconds

Fig. 7. The process of collapse of Sardabroud bridge truss

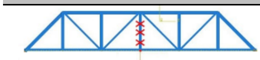
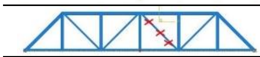
	SI	λ_{damage} kN	λ_0 kN	
	0.525	1490	3140	A1
	0.16	2940	3500	A2
	0.02	3430	3500	A3
	0.573	1620	3500	A4
	[illegible]21	1390	4980	A5

Fig. 8. Comparison of the moment of collapse of the bridge in reality with the m

(Figure (2)). In the simulation process, assuming that the speed of the truck was 20 km / h (Sardabroud bridge was built on a road turn); The truck takes 5.6 seconds to cross the bridge. In other words, it is assumed that in 2.8 seconds the truck is almost in the middle of the bridge. The stress distribution corresponding to these loading conditions is shown in Figure (7-a). At this time, the impact of a heavy load on the A1 pillar causes the loss of about 50% of the capacity of the structure. As much as 0.7 seconds total breakdown will occur in the bridge truss. The process of the bridge collapse is shown in Figure.

Figure (8) compares the moment of the bridge collapse in reality with the moment of collapse simulated in Abacus software. As can be seen in both images, the five vertical and diagonal elements along with the four horizontal elements are not broken at the top and bottom edges. This shows a good fit between the simulation results and the actual process of the bridge collapse event

4. Result

In this paper, the collapse process of the Sardabroud truss bridge was simulated using Abacus software. The results of the software show a good agreement of the collapse simulation process with what happened. On the other hand, using sensitivity analysis, it was shown that except for zero force elements, other vertical and oblique elements can play a key role in the backward failure of the structure. Therefore, they should be prevented inappropriate ways.

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