Case Study on Cable Loss of Cable Stayed Bridge due to Post Cable Rupture

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Abstract: The Ship shaw bridge is an asymmetric cable-stayed bridge with two planes of cables arranged in a fan shape spanning the Saguenay river which is located in Canada. The bridge is made of a double leg steel pylon and a composite deck supported by two box girders. The overall length of the bridge is 183.2 m the deck has an 11 m wide concrete slab that is 165 mm thick. Post cable loss scenarios lead to affect the response of the bridge and analysis are performed by using Midas Civil software with Nonlinear static analysis method. The Ship shaw bridge is an asymmetric cable-stayed bridge with two planes of cables arranged in a fan shape spanning the Saguenay river, which is located in Canada. The bridge is made of a double leg steel tower and a composite deck supported by two box girders. The overall length of the bridge is 183.2 m the deck has an 11 m wide concrete slab that is 165 mm thick. Post cable loss scenarios lead to affect the response of the bridge and analysis are performed by using Midas Civil software with Nonlinear static analysis method. Stays of cable-stayed bridges are critical structural elements which are subjected to abrasion, wind, vehicle impact, corrosion and malicious actions and these extreme scenarios may lead to severe damage and loss of cable(s). Such cable loss scenarios that can affect the response of the cable stayed bridge structure. Aim of study is to post cable loss scenarios lead to affect the response on cable stayed bridge. The objectives of this study are to analytically clarify influence of the cable loss on stability of cable stayed bridge. For this purpose, cable stress, deck shear force, deck bending moment, deck deflection is analyzed before and after the post cable rupture.
Keywords: Ship Shaw bridge, fan shape, pylon

Introduction

The cable-stayed system had been one of the first types of cable configuration adopted for the bridge construction in the history. Nowadays, the Stromsund Bridge in Sweden it is commonly recognized as the first example of modern cable stayed bridge [2]. The Stromsund Bridge completed in 1955 has one main span of 182.6 m, supported by two sets of stay cables radiating from the top of each pylon. The first cable-stayed bridge erected in Germany was the Theodor Heuss bridge across the Rhine River in Dusseldorf; the bridge is a three-span structure with a main span of 260 m [2].

Research Problem

Stays of cable-stayed bridges are critical structural elements which are subjected to abrasion, wind, vehicle impact, corrosion and malicious actions and these extreme scenarios may lead to severe damage and loss of cable(s). Such cable loss scenarios that can affect the response of the cable stayed bridge structure.

Aim

To study on post cable loss scenarios lead to affect the response on cable stayed bridge and inspect the stability of bridge.

Objectives

- To conduct an analysis of the shear force of bridge girders both before and after the occurrence of cable rupture.
- To conduct an analysis of the bending moment of bridge girders both before and after the occurrence of cable rupture.
- To conduct an analysis of the deflection of bridge girders both before and after the occurrence of cable rupture.
- To conduct an analysis of the cable stress of cables both before and after the occurrence of post cable rupture

Literature Review

The safety assessment of the stay cables is used to compare cable-stayed and extradosed bridges [3]. Static analysis is being conducted on the cable-stayed bridge featuring a fan-type design to assess its structural integrity. The staic analysis is conducted for all cables under normal conditions and different levels of corrosion in one cable and the failure of another cable due to excessive corrosion [8]. The bridge is a single-tower double-cable-plane structure, and the gulf adjacent to the bridge is located in a region that is commonly affected by typhoons [4].

Materials & Methods

Material properties and section properties of Ship shaw cable-stayed bridge are defined in Table 1. Bridge element model is shown in Figure 1. Cables are numbered as one to eight. Girders are numbered as rounded number which is from one to two. Bridge deck is divided as three lanes with 3 m width and LM1 axle load is applied along the bridge deck.LM1 axle load model is prescribed from clause 4.3.2+NA.2.12 to BS EN 1991-2:2003. Clause 5.7 of BS 5400-2:2000 Code of practice for design of steel bridges recommends that a bridge does not sag more than L/800. Maximum allowable displacement of ship shaw bridge girder is 0.229 m (183.2/800).

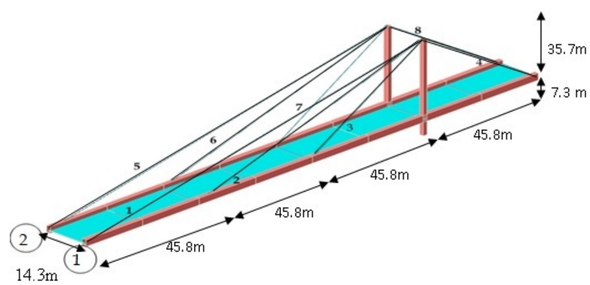

Figure 1: Ship shaw bridge element model [11]

Analysis steps

Nonlinear (bridge model consists the two types of material such as steel and concrete) static analysis method is to determine the static response of this model. The LM1 axle load is applied along the deck. The pre-tensioning force of each cable is assigned as $50kN$ to prevent the deflection of the cable. Load combination 1.0DL+1.0LL+1.0PS are used during the analysis (DL-Dead load, LL-Live load, PS-pretension load) Cable forces are analyzed before loss of cable and after loss of cables. Displacement of girder is analyzed before loss of cable and after loss of cable. Shear force and bending moment of girder is analyzed before loss of cable and after loss of cable.

Table 1: Material and section properties [11]

Element	Material	Type of Section	Dimension (m)	Cross sectional area (m^2)	Weight Density (kN/m^3)	Poisson ratio	Modulus of Elasticity (kN/m^2)
Girder	Steel	Box	1.5x3x0.05		77	0.3	$2x10^8$
Tower	Steel	Box	2.4x1.5x0.05		77	0.3	$2x10^8$
Cross Beam	Steel	Box	0.5x0.25x0.05		77	0.3	$2x10^8$
Cable	Steel	Solid Round		$585.9x10^{-6}$	77	0.3	$1.75x10^8$
Slab	Concrete (C40)		0.165 m thick		25	0.5	$36x10^6$

Table 2: Flexural time periods of Ship shaw cable-stayed bridge.

		Javanmardi et al [11]			Flexural time periods analysis result	
Mode shape	Deck Characteristic	Time periods (s)		Percentage difference (%)	Time periods (s)	Percentage difference (%)
		Experimental	Numerical			
Mode 1	Vertical/ asymmetric	1.85	2.09	12.9	1.83	-1.08
Mode 2	Vertical/ asymmetric	0.85	0.86	1.2	0.8	-5.88
Mode 3	Vertical/ asymmetric	0.57	0.57	0.0	0.57	0
Mode 4	Vertical/ asymmetric	0.38	0.42	10.5	0.4	±5.26

Bridge model validation

The present study, model validation is carried out by Flexural time period analysis and verified with experiment result which is used by Javanmardi et al [11]. Flexural time periods analysis (modal analysis) result is shown in Table 2.

Adopted Assigning Cable loss pattern

In this analysis, cable loss technique is adopted to section of sudden cable's cross-sectional area is assigned as $0.00005m^2$ and pre-tension load value is assumed as $0.00005kN$. Ultimate breaking load of cable is $878kN$ (ultimate strength of cable $1500MPa$ x cross sectional area of cable $585mm^2/1000$) [11].

Table 3: Scenarios and Conditions of Cables

Scenario No.	Condition of cable(s)
Scenario-0	Intact Condition
Scenario-1	Eliminate Cable 1
Scenario-2	Eliminate Cable 2
Scenario-3	Eliminate Cable 3
Scenario-4	Eliminate Cable 4

The following cable(s) loss scenarios are analysed. For scenario - 0, The LM1 model is applied along the deck. The pre-tensioning force of each cable is assigned as $50kN$ to prevent the deflection of the deck under dead load. Eight cable's cross section area and pretension load are assigned as 585x10^{-6} and $50kN$ respectively. The cross-sectional area of the ruptured cable (cable 1 in scenario - 1, cable 2 in scenario - 2, cable 3 in scenario - 3, cable 4 in scenario - 4) is assigned as 0.00005 m^2. Pretension load of the ruptured cable (cable 1 in scenario - 1, cable 2 in scenario -2, cable 3 in scenario -3, cable 4 in scenario -4) is assigned as 0.00005 kN. The LM1 model is applied along the deck during the scenario - 1, scenario - 2, scenario - 3, scenario - 4. Figure 2, Figure 3, Figure 4, Figure 5 are shown the cases by scenario 0, scenario 1, scenario 2, scenario 3, scenario 4.

Pretension load of the ruptured cable (cable 1 in scenario - 1, cable 2 in scenario -2, cable 3 in scenario -3, cable 4 in scenario -4) is assigned as 0.00005 kN. The LM1 axle load is applied along the deck during the scenario - 1, scenario - 2, scenario - 3, scenario - 4. Figure 1, Figure 2, Figure 3, Figure 4 are shown the cases by scenario 0, scenario 1, scenario 2, scenario 3, scenario4.

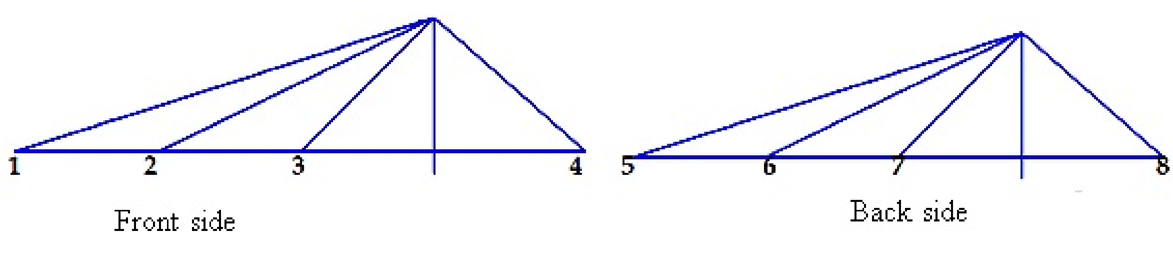

Figure 2: Scenario 0

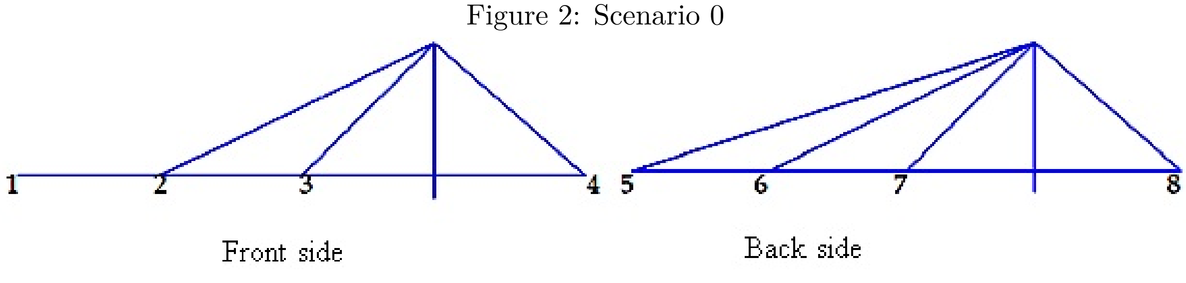

Figure 3: Scenario 1

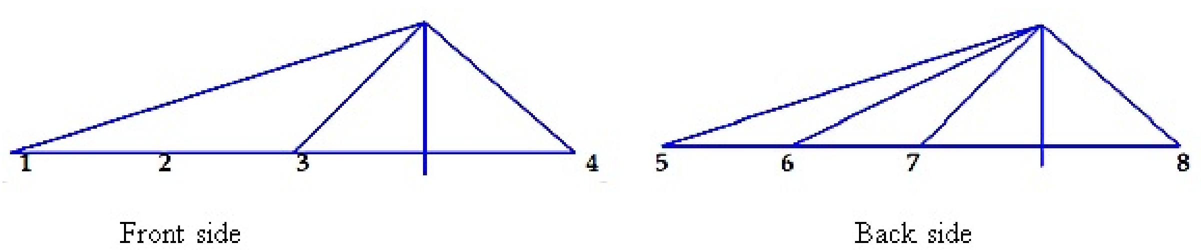

Figure 4: Scenario 2

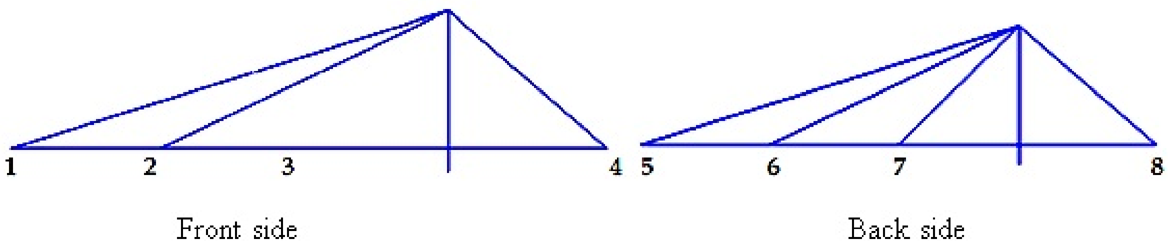

Figure 5: Scenario 3

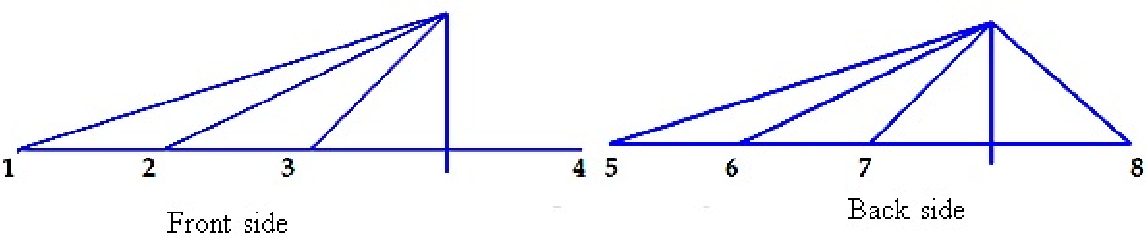

Figure 6: Scenario 4

Results & Discussion

Shear force of bridge girder No.1 and No.2 for all scenarios, bending moment of bridge girder No.1 and No.2 for all scenarios, displacement of bridge girder No.1 and No.2 for all scenarios and cable force of cables for all scenarios are shown by Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6.

Scenario 0: Intact condition of bridge structure

Maximum shear force and maximum bending moment of bridge girder No.1 and No.2 are 2062 kN , 2048kN and 15029 kNm,14910 kNm respectively. Maximum displacement of bridge girder No.1 and girder No.2 are 122mm & 124mm respectively. Cable force of cable 1, cable 2, cable 3, cable 4, cable 5, cable 6, cable 7, cable 8 are 525 kN,525 kN,528 kN,821 kN, 524 kN,524 kN,526 kN,819 kN respectively. Allowable displacement of girder No.1 and girder No.2 are 0.229m and cable force of all cables are not exceeded the ultimate breaking load of cable. So, structure is stable at scenario 0.

Scenario 1: Cable 1 losses

Maximum shear force and maximum bending moment of bridge girder No.1 and No.2 are 2161 kN , 2146 kN and 15751 kNm,15632

kNm respectively. Maximum displacement of bridge girder No.1 and girder No.2 are 492mm & 493mm respectively. Cable force of cable 2, cable 3, cable 4, cable 5, cable 6, cable 7, cable 8 are 770 kN, 617 kN, 989 kN, 610 kN, 610 kN, 613 kN, 942kN. Structure is unstable due to exceeding the allowable displacement limit of bridge girder and cable 4 and cable 8 are fail due to the exceeding the ultimate breaking load limit of cable.

Scenario 2: Cable 2 losses

Maximum shear force and maximum bending moment of bridge girder No.1 and No.2 are 2152 kN, 2137kN, 15685 kNm, 15556 kNm respectively. Maximum displacement of bridge girder No.1 and girder No.2 are 453mm and 455mm respectively. Cable force of cable 1, cable 3, cable 4, cable 5, cable 6, cable 7, cable 8 are 692 kN, 531 kN, 861 kN, 524 kN, 524 kN, 526 kN, 806 kN. Structure is unstable at scenario 2 due to exceeding the allowable displacement limit of bridge girder.

Scenario 3: Cable 3 losses

Maximum shear force and maximum bending moment of bridge girder No.1 and No.2 are 2134 kN, 2120 kN, 15751 kNm, 15632 kNm respectively. Maximum displacement of bridge girder No.1 and girder No.2 are 472 mm and 474 mm respectively. Cable force of cable 1, cable 2, cable 4, cable 5, cable 6, cable 7, cable 8 are 698 kN, 536 kN, 902 kN, 524 kN,524 kN, 526 kN, 806 kN. Structure is unstable at case 3 due to exceeding the allowable displacement limit of bridge girder and cable 4 is fail due to the the exceeding the ultimate breaking load limit of cable.

Maximum shear force and maximum bending moment of bridge girder No.1 and No.2 are 2170 kN, 2155kN, 15816kN, 15697 kN respectively. Maximum displacement of bridge girder No.1 and girder No.2 are 511 mm and 513 mm respectively. Cable force of cable 1, cable 2, cable 4, cable 5, cable 6, cable 7, cable 8 are 934 kN , 923 kN, 784 kN, 785 kN ,786 kN, 790 kN, 1210 kN, 878 kN. Structure is unstable at case 4 due to exceeding the allowable displacement limit of bridge girder and cable 1, cable2 and cable 4 are fail due to the the exceeding the ultimate breaking load limit of cable.

Conclusions

The shear force is increased on bridge girder due to cable losses. The bending moment is increased on bridge girder due to cable losses. The deflection is increased on bridge girder due to cable losses. The cable force is increased on cables due to cable losses. The amount of variation in deflection, shear force, and bending moment are highest due to the losses of the cable 4. Deflection variation was increased by 4.1%, compare to scenario 0. Structure is unstable at scenario 1, scenario 2, scenario 3 and scenario 4 due to exceeding the allowable displacement limit of bridge girder and multiple cable losses.

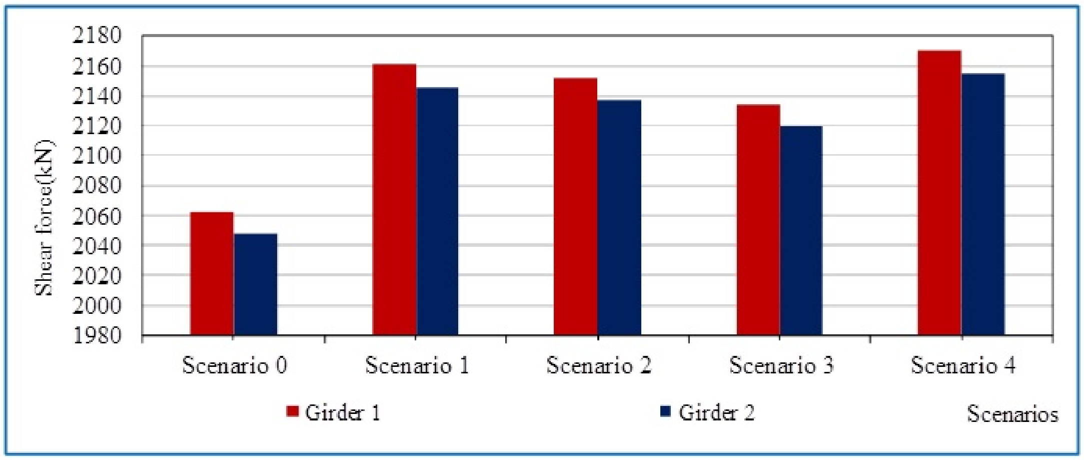

Figure 7: Shear force of bridge girder No.1 and No.2 for all scenarios

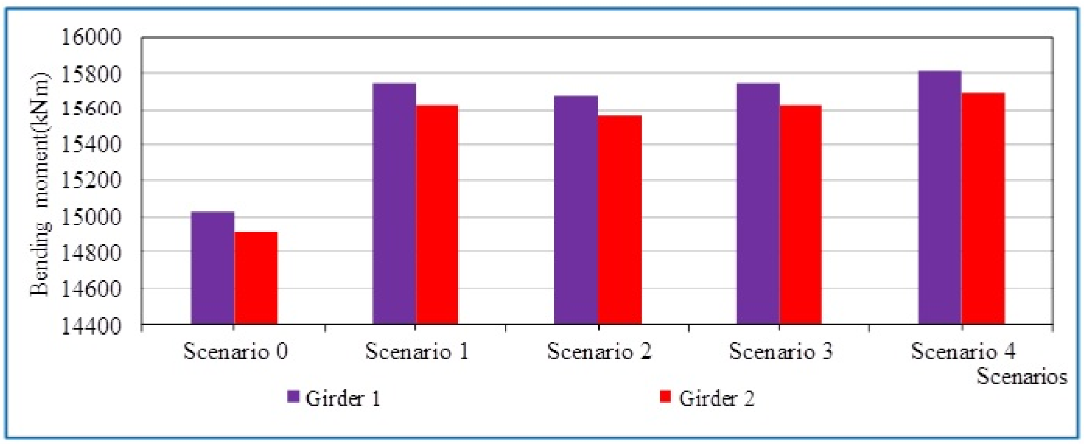

Figure 8: Bending moment of bridge girder No.1 and No.2 for all scenarios

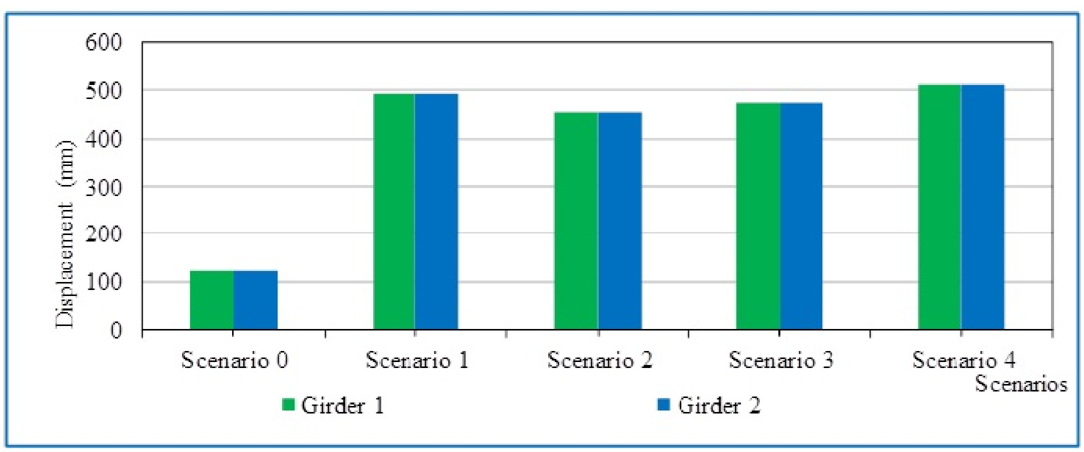

Figure 9: Displacement of bridge girder No.1 and No.2 for all scenarios

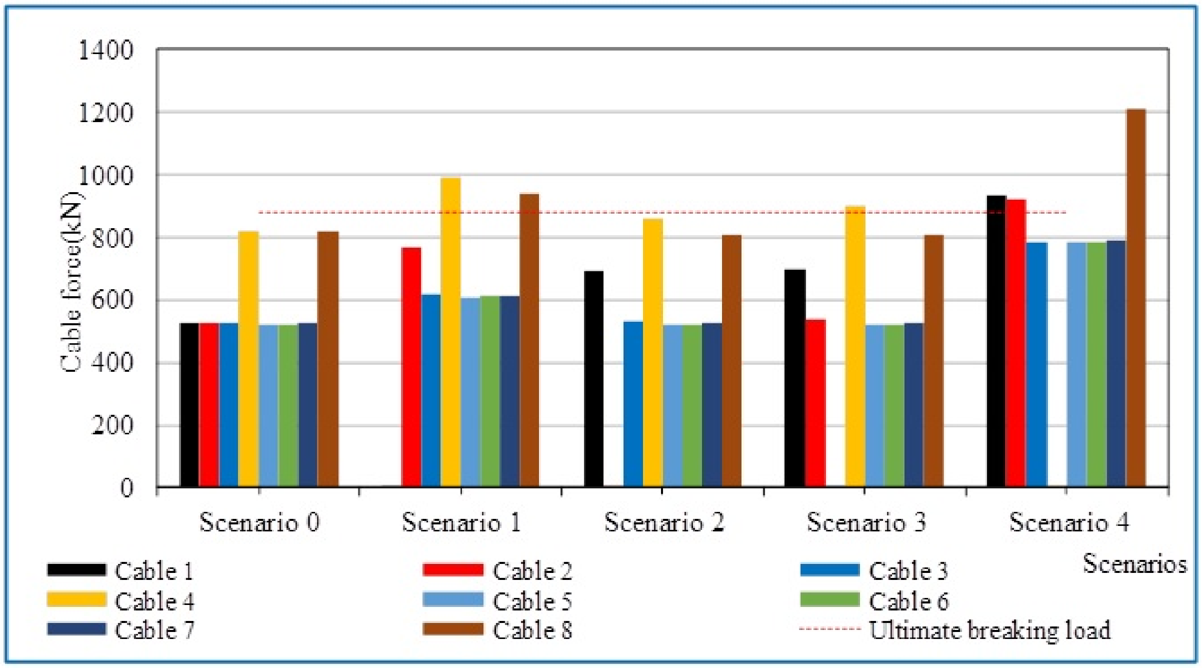

Figure 10: Cable force for all scenarios

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