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The influence of the Young modulus on two elements of a Warren truss on the dynamic behavior of the structure

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Abstract. *The present work aims to determine the natural frequencies for a structure with Warren truss by changing the modulus of elasticity to two of the elements of the structure are keeping the same length of the elements. A numerical study is carried out by means of a 3D FE model of a Warren truss, simulating the dynamic interaction of beams with trusses.*

Keywords: *Warren truss, mode shape, natural frequency*

1. Introduction

Warren truss structures are popular construction used in various engineering fields and among them, steel rectangular tube trusses have been widely applied in large engineering structures, such as stadiums, bridges, concert halls, and offshore platforms, International Space Station because of their architecturally attractive shapes and favorable structural properties [1–2-4-5]. Is made up of longitudinal members linked only by angled cross-members that create successively inverted equilateral triangle-shaped sections along its length.

Loads on the diagonals vary between compression and tension, as they approach the center, with no vertical elements, but parts in the center must withstand both tension and compression in response to live loads [3].Truss structures are popularly used in various engineering fields [1–4].

Many investigations have been carried out related to steel rectangular truss structures [6–7].

In this study, structural steel, from the Solidwork library, rectangular tubes with the dimensions of 50x30x2.6 mm and 120x80x8 mm were used.

With the help of Solidwork software we have found natural freqvency and modal shapes for the first five vibration modes. Analized cases and the Young's modulus are given in table 1.

In case 1, the elements in the truss are of the same modulus of elasticity 210000N/mm^2, the other cases 2...16 are with the modulus of elasticity different 160000 N/mm^2. Warren truss is fixed at the both ends.

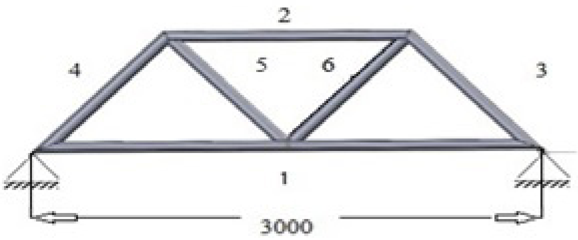

Figure 1. Six-bar truss

Length of span of the considered Warren truss is of 3000mm.

Table 1. Analized cases

Case	Elements	Young's Modulus
1	-	210000N/mm^2
2	1-2	160000 N/mm^2
3	1-3	160000 N/mm^2
4	1-4	160000 N/mm^2
5	1-5	160000 N/mm^2
6	1-6	160000 N/mm^2
7	2-3	160000 N/mm^2
8	2-4	160000 N/mm^2
9	2-5	160000 N/mm^2
10	2-6	160000 N/mm^2
11	3-4	160000 N/mm^2
12	3-5	160000 N/mm^2
13	3-6	160000 N/mm^2
14	4-5	160000 N/mm^2
15	4-6	160000 N/mm^2
16	5-6	160000 N/mm^2

2. Analytical approach

Elements are stressed in tension or compression for a double hinged truss. In this case the relationship of longitudinal vibrations will be used.

Applying the local coordinate system for the right (x, z) truss element shown in Fig. 2 [15].

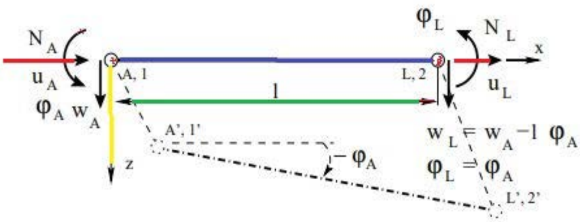

Figure 2. Truss bar

The transfer equations for longitudinal vibration of a truss bar are:

$$u_L = u_A\, coskl - \frac{N_A}{EA}\frac{1}{k}\, sinkl \tag{1}$$

$$w_L = wA - \varphi_A l \tag{2}$$

$$\varphi_L = \varphi_A \tag{3}$$

$$N_L = -u_A EAk\, sinkl - N_A\, coskl \tag{4}$$

where:

u_A, u_L – axial displacements at the beginning

w_A, w_L – transverse displacements at A and L;

φ_A, φ_L – rotation at A and L;

N_A, N_L – axial forces at A and L;

$\kappa = \omega \sqrt{m/EA} = \omega \sqrt{\rho/E}$ – wav enumber;

ω – frequency of vibration;

$m = \rho A$ – mass per unit length;

ρ – mass density;

A – cross-sectional area;

E – elastic or Young's modulus;

ℓ – length of the element

2. Numerical modal analyzes

Solidworks is used to determine the natural frequencies and mode shapes which depend on the geometry of truss analyzed, material properties, and support condition.

It used a Warren-type truss, hinged at both ends, where it is changed the modulus of elasticity at two elements of the structure in order to determine the natural frequencies and mode shapes. The whole assembly was tested using gravitational acceleration. Figure 3 illustrates the first 5 vibration modes.

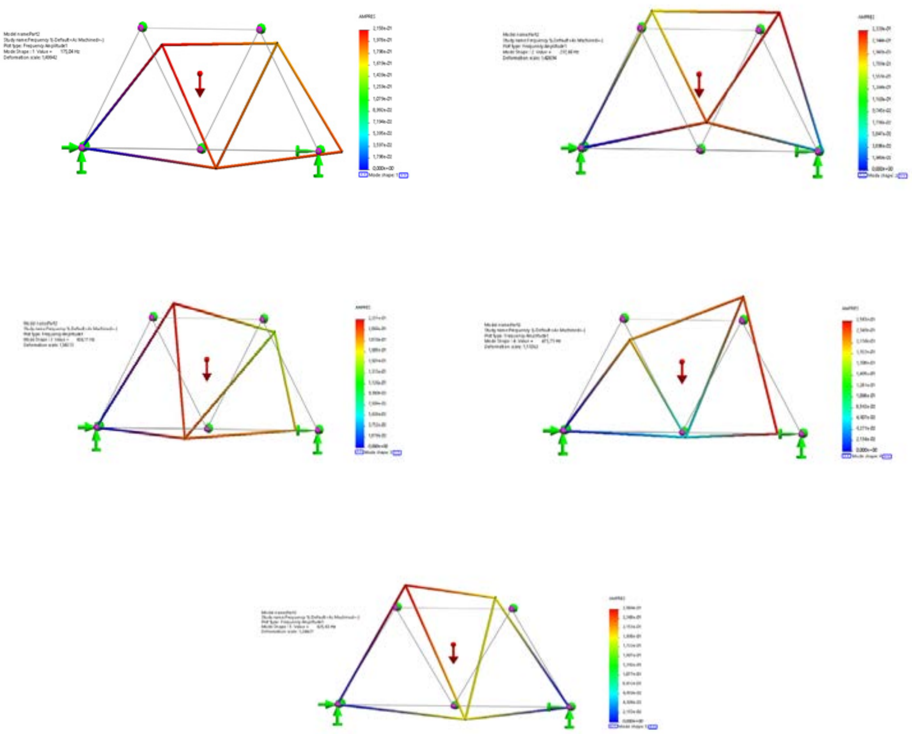

Figure 3. Mode shapes for seven elements warren truss.

Table 2 it shows the natural frequencies (f_n) for simulation for case of bars with section 50x30x2.6.mm Table 3 presents the relative frequencies shift (e_n) (n=1, 2 ...5), where e_n is calculated with the relationship:

$$e_n = \frac{f_{Un} - f_{Dn}}{f_{Un}} \tag{5}$$

f_{Un} – natural frequencies for the structure with E=210000N/mm^2

f_{Dn} - the natural frequencies for the modified structure.

Table 2. Natural frequencies for truss bar with cross section 50x30x2.6mm

Elements	F_1 [Hz]	F_2 [Hz]	F3 [Hz]	F4 [Hz]	F5 [Hz]
-	52,183	54,8	61,89	68,08	72,57
1-2	49,499	51,64	58,55	65,04	66,86
1-3	49,087	50,93	58,93	67,41	68,08
1-4	49,125	50,93	58,85	67,43	68,08
1-5	49,8	50,72	58,73	65,31	67,96
1-6	49,778	50,71	58,7	65,31	68,1
2-3	49,43	53,71	59,35	64,97	69,04
2-4	49,47	53,71	59,26	64,97	69,1
2-5	49,668	53,74	59,18	62,68	70,24
2-6	49,638	53,73	59,2	62,68	70,3
3-4	49,847	52,56	59,5	64,079	69,45
3-5	50,008	52,73	59,23	65,35	70,49
3-6	49,548	52,87	59,77	65,32	70,33
4-5	49,604	52,87	59,69	65,32	70,29
4-6	50,022	52,73	59,14	65,35	70,62
5-6	50,245	52,58	59,48	62,9	71,19

Table 3. Relative frequency shift for truss bar cross section 50x30x2.6mm

Elements	ε_1[%]	ε_2 [%]	ε_3 [%]	ε_4 [%]	ε_5 [%]
-	0	0	0	0	0
1-2	5,14	5,76	5,90	4,47	7,86
1-3	5,93	7,06	6,00	4,99	6,18
1-4	5,86	7,06	6,50	4,66	6,18
1-5	4,57	7,45	6,70	4,07	6,35
1-6	4,61	7,46	5,16	4,07	6,16
2-3	5,28	1,99	4,12	4,57	4,86
2-4	5,20	2,80	4,25	4,57	4,78
2-5	4,82	1,95	4,38	7,93	3,21
2-6	4,88	1,95	4,36	7,93	3,12
3-4	4,48	4,09	3,87	7,60	4,30
3-5	4,17	3,89	4,21	4,02	4,20
3-6	5,05	3,53	3,43	4,06	3,08
4-5	4,94	3,52	3,56	4,06	3,84
4-6	4,14	3,78	4,45	4,02	2,68
5-6	3,71	4,07	3,90	7,62	1,91

Tables 4 presents the natural frequencies for simulation for case of bars with section 120x50x8 mm and table 5 the relative frequency shift for this section.

Table 4. Natural frequencies for truss bar with cross section 120x80x8mm

Elements	f_1 [Hz]	f_2 [Hz]	f_3 [Hz]	f_4 [Hz]	f_5 [Hz]
-	133,13	140,97	144,14	161,43	166,44
1-2	125,91	132,86	134,48	154,36	155,58
1-3	124,44	130,61	135,44	156,28	161,42
1-4	126,25	130,34	134,06	155,86	161,42
1-5	127,32	130,45	134,33	154,98	156,81
1-6	125,91	130,15	134,99	154,98	159,41
2-3	125,47	137,97	140,51	154,2	157,59
2-4	126,9	136,83	139,84	154,2	158,02
2-5	127,06	137,68	139,76	148,86	160,23
2-6	125,95	137,6	140,42	148,86	161,75
3-4	127,5	134,65	139,75	157,39	161,42
3-5	127,48	135,43	139,92	155,06	159,2
3-6	125,36	135,28	141,43	154,99	161,32
4-5	127,43	135,85	139,23	154,99	159,71
4-6	128,02	135,39	138,13	155,06	161,76
5-6	128,06	134,72	140,08	149,37	163,23

Table 5. Relative frequency shift for truss bar cross section 120x80x8mm

Elements	ε_1[%]	ε_2 [%]	ε_3 [%]	ε_4 [%]	ε_5 [%]
-	-	-	-	-	-
1-2	5,42	5,75	6,70	4,38	7,00
1-3	6,53	7,35	6,04	4,60	5,89
1-4	5,60	7,54	6,99	4,16	5,56
1-5	4,36	7,46	6,81	4,00	5,79
1-6	5,42	7,68	6,35	4,00	4,22
2-3	5,75	2,13	3,90	4,48	5,32
2-4	4,68	2,94	4,00	4,48	5,06
2-5	4,56	2,33	3,04	7,79	3,73
2-6	5,39	3,78	3,48	7,79	4,00
3-4	4,23	4,48	3,05	2,50	4,02
3-5	4,24	3,93	4,20	3,95	4,35
3-6	5,84	4,04	3,20	3,99	3,08
4-5	4,28	3,63	3,41	3,99	4,04
4-6	3,84	3,96	4,17	3,95	2,81
5-6	3,81	4,43	3,50	7,47	1,93

Figure 4 shows the relative frequencies shift when 2 elements have the modulus of elasticity E=160000 N/mm^2, respective: 1-2, 1-3, 1-4, 1-5, 1-6. With the black color we have the cross section 120x80x8mm, and with yellow color we have cross section 50x30x2.6.mm.

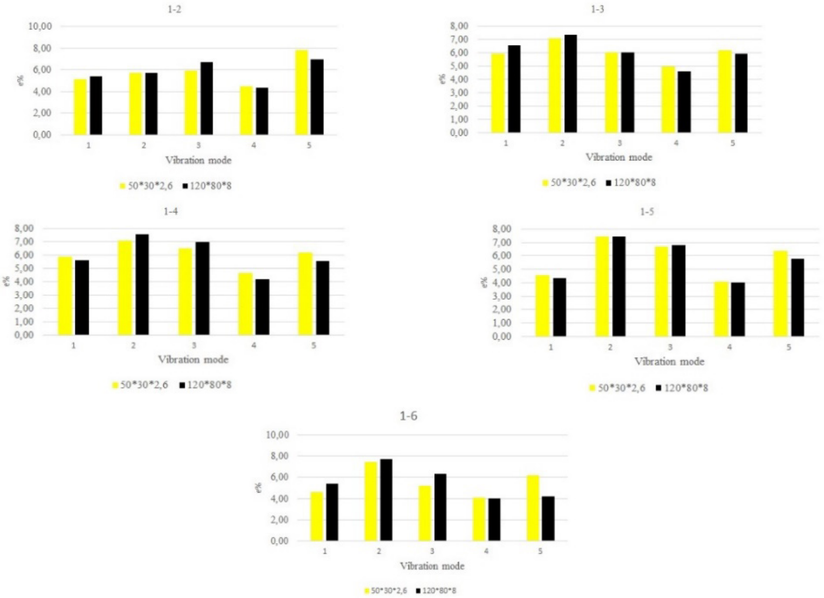

Figure 4. Comparison of the relative frequency shift in case of elements 1-2, 1-3, 1-4, 1-5, 1-6 have E=160000 N/mm^2

Figure 5 shows the relative frequencies shift of the natural frequencies when elements 2-3, 3-4, 2-5, 2-6 have the modulus of elasticity E=160000 N/mm^2.

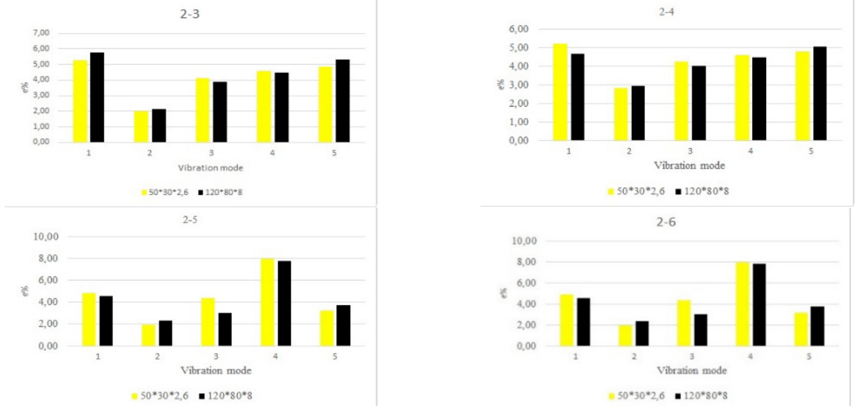

Figure 5. Comparison of the relative frequency shift in case of elements 2-3, 2-4, 2-5, 2-6, have E=160000 N/mm^2

Figure 6 shows the relative deviations of the natural frequencies when 2 elements have the modulus of elasticity E=160000 N/mm^2, respective: 3-4, 3-5, 3-6

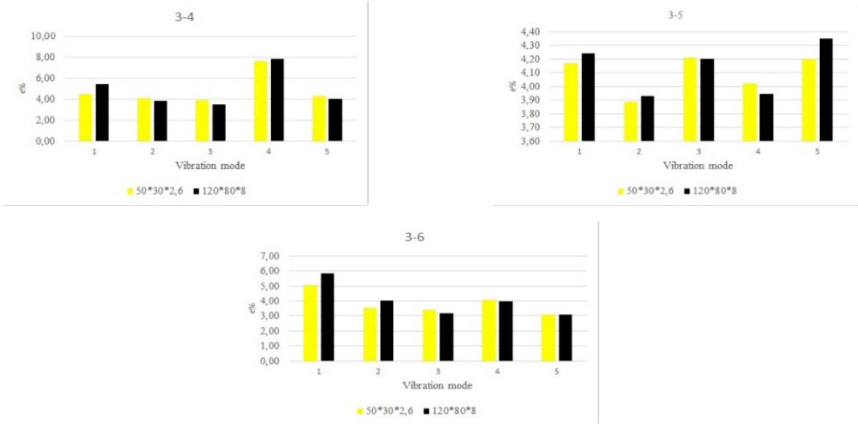

Figure 6. Comparison of the relative frequency shift in case of elements 3-4, 3-5, 3-6 have E=160000 N/mm^2

Figure 7 shows the relative deviations of the natural frequencies when 2 elements have the modulus of elasticity E=160000 N/mm^2, respective: 4-5, 4-6

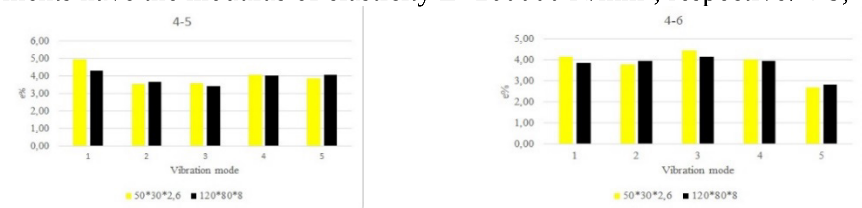

Figure 7. Comparison of the relative frequency shift in case of elements 4-5, 5-6 have E=160000 N/mm2

Figure 8 shows the relative deviations of the natural frequencies when 2 elements have the modulus of elasticity E=160000 N/mm^2, respective 5-6.

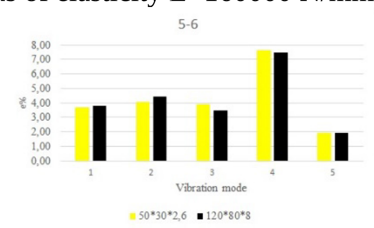

Figure 8. Comparison of the relative frequency shift in case of elements 5-6 have E=160000 N/mm^2

4. Conclusion

A series of sixteen tests was performed on the Warren type beam elements to illustrate the influence of the modulus of elasticity in the behavior of the truss elements.

From figure 3, it follows that the allure of the vibration modes do not change regardless of whether the modulus of elasticity was reduced at the value of 1600000 N/mm^2.

The numerical modal analysis started from the structure with all the elements from the same material (structural steel E=210000N/mm^2) and natural frequencies were obtained.

Subsequently, 2 elements were modified where the modulus of elasticity was intentionally reduced to the value 160000 N/mm^2. The natural frequencies for the first 5 vibration modes were determined and their relative frequency shift was calculated.

From the analysis of figures 4 -8, it can be seen that the relative frequency shift is not influenced by the cross section chosen for the same length of the structural element.

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