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VIBRATION ANALYSIS OF CRACK DEVELOPED ON BRIDGES USING ANSYS

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Abstract

The cracks induced in bridge may result in change of natural frequency. This change in natural frequency may cause damage in case of resonance which causes amplitude build up. It is therefore necessary to determine the effect of crack on natural frequency of straight bridge. The objective of current research is to investigate the effect of crack design parameters on vibrational characteristics of bridge. CAD modeling of straight bridge using ANSYS design modeler. Free vibration (modal analysis) analysis on base design of curved bridge to determine natural frequencies and mode shapes. Study on effect of I shaped steel girder dimension on vibration characteristics of bridge using Taguchi response surface method. Inducing single crack on base design and reconducting modal analysis to determine mode shapes and natural frequencies Study on effect crack dimensions parameters on vibration characteristics using Taguchi response surface method

Keywords: Bridge, CAD, Frequency, Vibration, Crack, ANSYS.

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1. Introduction

We recognize that all structures are part of the infrastructure and each one works together. The bridges take a special role, due its function to connect two different points, crossing valleys, rivers, lakes and cliffs. Bridges are needed on land transportation infrastructure because they connect different points that usually can be inaccessible. If we analyze a single bridge crossing a river, it can have many views, depending on each person's perspective [3]

a. A person who lives in the city can visualize the bridge as a simple access to schools, parks and theaters, or a simple way to visit a family member.
b. An engineer or architect visualizes the bridge as a way to connect the road with two points of the city, such as hospitals or fire stations.
c. From the business community, the bridge can be viewed as access to different areas for trade, distribution of goods and services.

Depending on the needs of the society to have a bridge, it would be its importance. A bridge that serves as a quick link to recreational parks with a low traffic flow will have less impact than a bridge crossing a large river and connecting two points of the city with high traffic flow [1]. Taking into account the sentence above, we can realize that bridges are not built arbitrarily; a whole planning should be performed including design, construction, operation and maintenance of the structures.

FEM and ANSYS

The FEM technique is a beneficial tool for calculating mathematical equations in a variety of engineering problems. The method was suggested in the aerospace industry as a tool designed for assessing anxiety in challenging jet systems. It is developed from the matrix analysis procedure, which is utilized in aircraft design. Each researcher and practitioner has made significant progress in their respective fields. The finite element methodology's main principle is to break down a body otherwise structure into smaller, finite-size components known as limited elements.' The variables associated with a limited set of connections known as nodes or nodal points are investigated in the initial frame and structure

2. Methodology

The first step involves material definition. The geometry analysed comprises of structural steel material and concrete material. The material properties of structural steel are shown in figure 4.1 below. The material properties of steel are taken from ANSYS library file [43].

Properties of Outline Row 5: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7850	kg m^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion	1.2E-05	C^-1		
6	Isotropic Elasticity				
7	Derive from	Young'...			
8	Young's Modulus	2E+11	Pa		
9	Poisson's Ratio	0.3			
10	Bulk Modulus	1.6667E+11	Pa		
11	Shear Modulus	7.6923E+10	Pa		

Figure 1. Steel Material Properties [43]

Properties of Outline Row 4: concrete paper

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2448	kg m^-3		
4	Isotropic Elasticity				
5	Derive from	Young'...			
6	Young's Modulus	28000	MPa		
7	Poisson's Ratio	0.2			
8	Bulk Modulus	1.5556E+10	Pa		
9	Shear Modulus	1.1667E+10	Pa		

Figure 2. Concrete Material Properties [44]

The material properties of concrete for bridge deck are shown in figure 5 below. The material properties of concrete are taken from literature [44].

The CAD model of bridge along with I shaped girder is developed in ANSYS design modeller using sketch and extrude tools. Initially bridge deck is modelled followed by I shaped girders. The dimensional variables are defined in ANSYS design modeller. These dimension variables are H1 and V2 as shown in figure 4.3 below. H1 is the width of girder and V2 is the thickness.

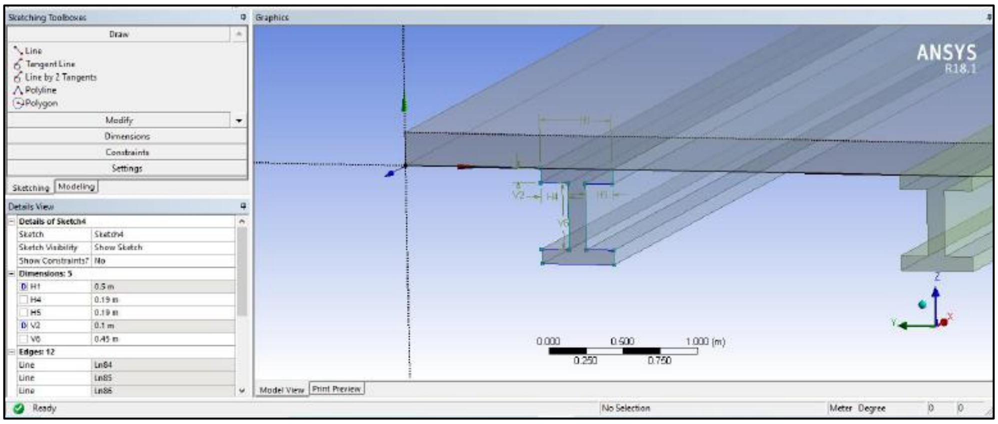

Figure 3. Selection of dimensional variables

2.1 Response Surface Optimization

The response surface method (RSM) is a “set of mathematical and statistical techniques that are useful for analyzing problems in which several independent variables affect a dependent variable or response” [45]. The goal is to optimize this response. “We denote the independent variables of X1, X2, X3, X4 ……. Xn and assume that these variables are continuous and can be controlled by the experimenter with negligible error” [46]. The relationship between the dependent variable and the independent variable can be represented as

$$y = f(X_1, X_2, X_3, X4 \ldots\ldots X_n) + \varepsilon$$

where ε represents the noise or error observed in the "y" response.

If we denote the expected answer with

$$E(y) = f(X_1, X_2, X_3, X4 \ldots\ldots X_n) = \eta$$

then, the surface represented by

$$f(X_1, X_2, X_3, X4 \ldots\ldots X_n) = \eta$$

is called the response surface [46]. The input parameters selected for optimization are shown in table 5.3 below and represented in figure below.

3. Result and Discussions

The vibrational analysis is conducted on bridge deck to determine natural frequencies and corresponding mode shapes. The 1st 5 natural frequencies are determined for bridge without any crack.

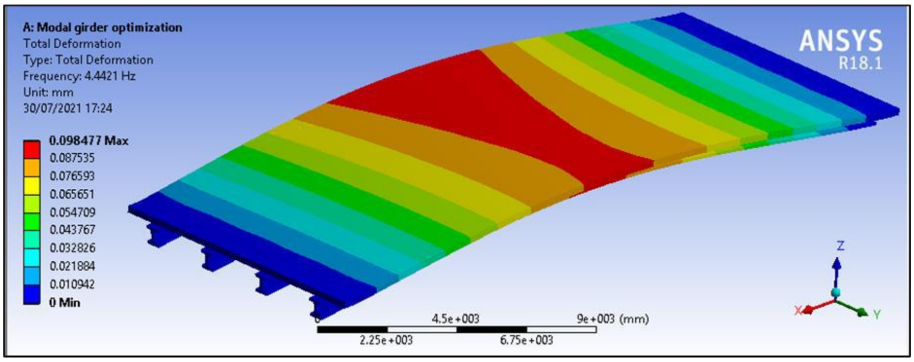

Figure 4. 1st mode shape of un-cracked geometry

The 1st natural frequency of bridge without any crack is 4.44Hz as shown in figure 5.1 above. The frequency mode shape is transverse type and maximum amplitude of deformation obtained is .0984mm.

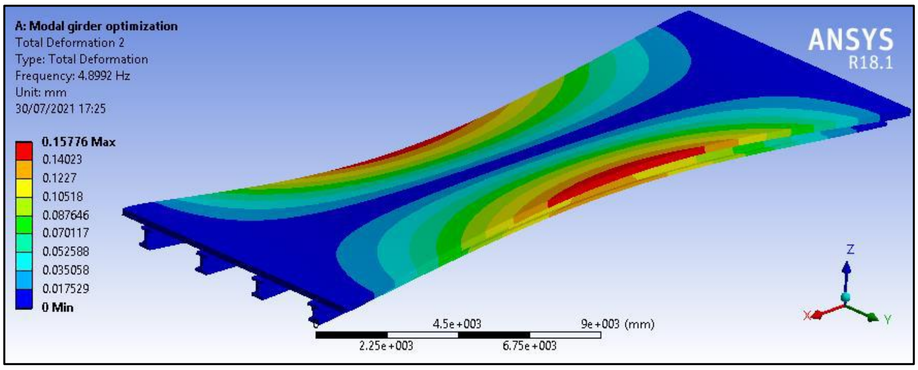

Figure 5. 2nd mode shape of un-cracked geometry

Table 1. Natural frequency comparison table

Design Type	1st natural frequency	2nd natural frequency	3rd natural frequency	4th natural frequency	5th natural frequency
Without crack	4.4421	4.8992	9.1098	12.962	14.272
With crack	4.6439	5.0907	9.237	13.328	14.488

Table 2. Natural frequency deformation table

Design Type	1st natural frequency	2nd natural frequency	3rd natural frequency	4th natural frequency	5th natural frequency
Without crack	.0984	.157	.183	.1018	.1609
With crack	.0991	.1586	.18394	.10233	.16061

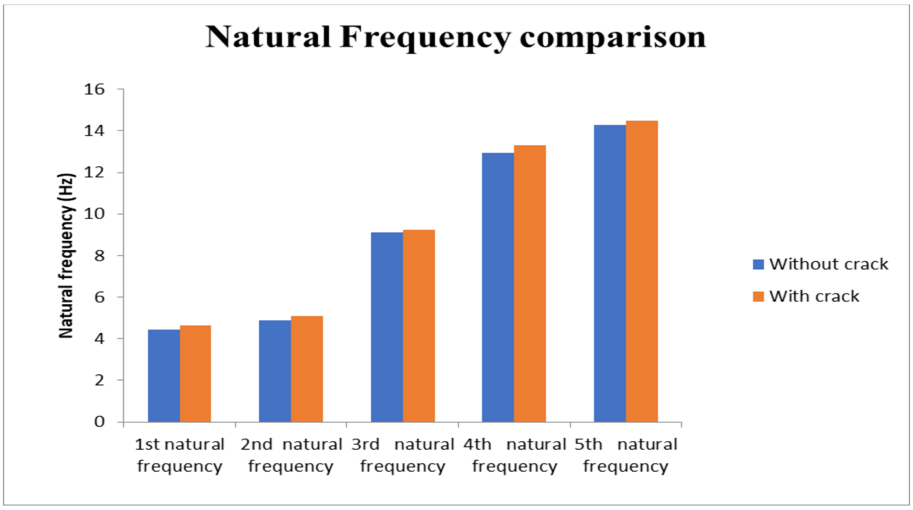

Figure 6. Natural frequency comparison

The natural frequency comparison plot is obtained from the analysis. The natural frequency of bridge without crack is observed to be higher than bridge without crack. This is observed for all the natural frequencies.

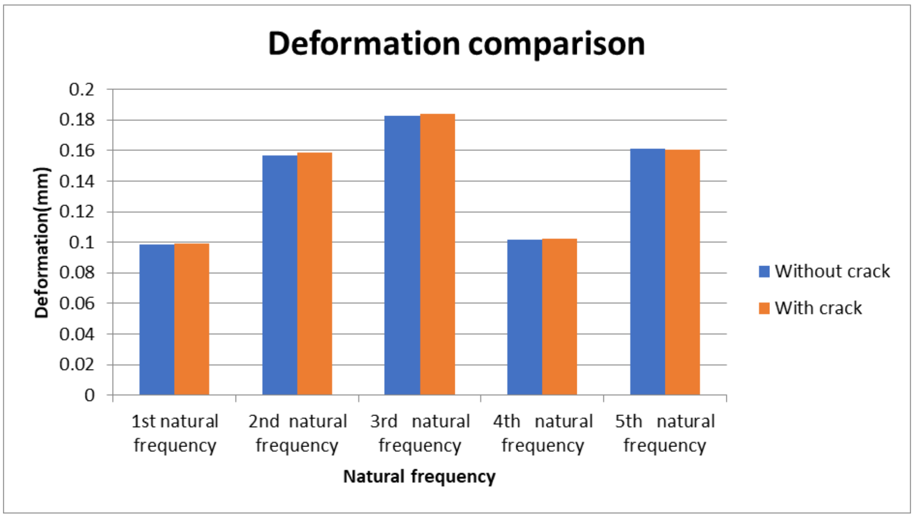

Figure 7. Natural frequency deformation comparison

The natural frequency deformation plot is obtained from the FEA analysis. For 1st 4 natural frequencies, the deformation is observed to be higher for bridge with crack and is observed to be lower for bridge without crack. For 5th natural frequency, the bridge without crack has higher deformation as compared to bridge with crack.

3.1 Effect of girder variables on vibration characteristics (using Response Surface Optimization)

The response surface optimization of bridge is conducted using Taguchi Design of Experiments. The design points are generated with different values of girder_width and flange_thickness using central composite design scheme. The design points generated are shown in chart 5.6 below. The deformation obtained for 1st, 2nd, 3rd ,4th and 5th natural frequencies are evaluated using techniques of FEA. The deformation values are shown in column D,E,F,G and H.

Table of Outline A2: Design Points of Design of Experiments

	A	B	C	D	E	F	G	H
1	Name	P1 - girder_width (m)	P2 - flange_thickness (m)	P3 - Total Deformation Maximum (mm)	P4 - Total Deformation 2 Maximum (mm)	P5 - Total Deform... 3 Maximum (mm)	P6 - Total Defor... 4 Maximum (mm)	P7 - Total Deforma... 5 Maximum (mm)
2	1 DP 0	0.5	0.1	0.098477	0.15776	0.18328	0.10186	0.16094
3	2	0.45	0.1	0.10769	0.16782	0.19328	0.11495	0.17205
4	3	0.55	0.1	0.091206	0.14947	0.1738	0.092422	0.14948
5	4	0.5	0.09	0.10022	0.16063	0.18645	0.104	0.16319
6	5	0.5	0.11	0.096983	0.15519	0.18023	0.099914	0.15889
7	6	0.45	0.09	0.10948	0.17086	0.1966	0.1175	0.17365
8	7	0.55	0.09	0.09273	0.15203	0.17685	0.094199	0.15192
9	8	0.45	0.11	0.10599	0.16493	0.19008	0.11252	0.17034
10	9	0.55	0.11	0.089722	0.14706	0.17088	0.090687	0.14727

Figure 8. DOE chart for different dimensions of girder_width and flange_thickness

3.2 Effect of crack variables on vibration characteristics (using Response Surface Optimization)

The response surface optimization of bridge with crack on I shaped girder is conducted using Taguchi Design of Experiments. The design points are generated with different values of crack_minor and crack_major using central composite design scheme. The design points generated are shown in chart 5.32 below. The deformation obtained for 1st, 2nd, 3rd ,4th and 5th natural frequencies are evaluated using techniques of FEA. The deformation values are shown in column D,E,F,G and H.

Table of Schematic B2: Design of Experiments (Central Composite Design : Auto Defined)

	A	B	C	D	E	F	G	H
1	Name	P8 - crack_minor (m)	P9 - crack_major (m)	P3 - Total Deformation Maximum (mm)	P4 - Total Deformation 2 Maximum (mm)	P5 - Total Deformation 3 Maximum (mm)	P6 - Total Deformation 4 Maximum (mm)	P7 - Total Deformation 5 Maximum (mm)
2	1 DP 0	0.018	0.09	0.099135	0.1586	0.18394	0.10233	0.16061
3	2	0.0162	0.09	0.099089	0.15859	0.18395	0.10231	0.16062
4	3	0.0198	0.09	0.098788	0.15842	0.18396	0.10212	0.16076
5	4	0.018	0.081	0.099217	0.15864	0.18392	0.10242	0.16064
6	5	0.018	0.099	0.099065	0.15856	0.18393	0.10235	0.16064
7	6	0.0162	0.081	0.098792	0.15841	0.18395	0.10219	0.16073
8	7	0.0198	0.081	0.098952	0.1585	0.18395	0.10224	0.16073
9	8	0.0162	0.099	0.099241	0.15863	0.18389	0.10243	0.16057
10	9	0.0198	0.099	0.098743	0.1584	0.18396	0.1021	0.16076

Figure 9. Design points generated for bridge with crack

4. Conclusion

The use of FE computer simulation is a viable tool in determining the vibrational characteristics of bridge with I shaped girders. From the modal analysis conducted on straight bridge, the type and nature of bridge deformation is determined which provided significant information on critical regions and natural frequencies. The 1st response surface optimization technique is used to determine the effect of I shaped girder design variables on vibrational characteristics. Similarly, 2nd response surface optimization technique is used to determine the effect of crack dimensions on vibrational characteristics of bridge.

The detailed findings are: -

1. From the response surface optimization on girder dimensions, it was observed that the 5th frequency maximum deformation is obtained for flange_thickness ranging from .091mm to .109mm and girder_width ranging from .45mm to .48mm.

2. From the response surface optimization on crack dimensions, it was observed that the maximum 5th frequency deformation is observed for crack_major dimensions ranging from .082m to .098m and crack_minor dimensions ranging from .019m to .0195m. The deformation is minimum for regions shown by dark blue colored region.
3. For 1st frequency deformation, crack_minor dimension has higher sensitivity percentage (69.5%) as compared to crack_major (23.61%) dimension which signifies that crack_minor has higher effect on 1st frequency deformation and crack_major has lower effect on 1st frequency deformation.
4. For 2nd frequency deformation, crack_minor dimension has higher sensitivity percentage (70.1%) as compared to crack_major dimension (29.9%) which signifies that crack_minor has higher effect on 2nd frequency deformation and crack_major has lower effect on 2nd frequency deformation.
5. For 3rd frequency deformation, crack_minor dimension has higher sensitivity percentage (33.23%) as compared to crack_major dimension (22.92%) which signifies that crack_minor has higher effect on 3rd frequency deformation and crack_major has lower effect on 3rd frequency deformation.
6. For 4th frequency deformation, crack_minor dimension has higher sensitivity percentage (76.86%) as compared to crack_major dimension (20.44%) which signifies that crack_minor has higher effect on 4th frequency deformation and crack_major has lower effect on 4th frequency deformation.
7. For 5th frequency deformation, crack_minor dimension has higher sensitivity percentage (86.6%) as compared to crack_major dimension (13.54%) which signifies that crack_minor has higher effect on 5th frequency deformation and crack_major has lower effect on 5th frequency deformation.
8. For 1st frequency deformation, the girder_width has higher sensitivity percentage of 83.45 whereas flange_thickness has lower sensitivity percentage of 16.39 which shows girder_width has higher effect on 1st frequency deformation and flange_thikness has lower effect on 1st frequency deformation.
9. For 2nd frequency deformation, the girder_width has higher sensitivity percentage of 77.06 whereas flange_thickness has lower sensitivity percentage of 22.75 which shows girder_width has higher effect on 1st frequency deformation and flange_thikness has lower effect on 2nd frequency deformation.
10. For 3rd frequency deformation, the girder_width has higher sensitivity percentage of 75.77 whereas flange_thickness has lower sensitivity percentage of 24.15 which shows girder_width has higher effect on 1st frequency deformation and flange_thikness has lower effect on 3rd frequency deformation.
11. For 4th natural frequency deformation, the girder_width has higher sensitivity percentage of 83.94 whereas flange_thickness has lower sensitivity percentage of 15.28 which shows girder_width has

higher effect on 1st frequency deformation and flange_thikness has lower effect on 4th frequency deformation.

12. For 5th natural frequency deformation, the girder_width has higher sensitivity percentage of 85.51 whereas flange_thickness has lower sensitivity percentage of 16.28 which shows girder_width has higher effect on 1st frequency deformation and flange_thikness has lower effect on 4th frequency deformation.

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