Stability Analysis of Bridge Structures Using Modal Analysis

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Abstract - *A bridge is a man-made structure built to avoid physical obstacles without closing the path beneath it, such as a body of water, a valley, or a road. The objective of current research is to investigate the vibration characteristics of bridge structure using different materials. The modal analysis of bridge structure is conducted using ANSYS simulation package. The materials investigated in the research is concrete material, silicone rubber and neoprene rubber. The mode shapes, natural frequency and mass participation factor is evaluated for different bridge materials. From modal analysis of silicone rubber material, the critical region is found to be at crash barrier which exhibited maximum deformation and susceptible to amplitude build up during resonance and for neoprene rubber material, the maximum deformation is observed to be at bearing region whereas the bridge structure and crash barrier have lower deformation*

Key Words: Bridge, structural analysis, damage

1.INTRODUCTION

A bridge is a "man-made structure built to avoid physical obstacles without closing the path beneath it, such as a body of water, a valley, or a road. It is designed to ensure passage over an obstacle. The first bridges made by humans were probably spans of cut wooden logs or planks and eventually stones, using a simple arrangement of support and cross beam" [1]. The first arched type bridge structures were developed by Romans.

Figure 1: Bridge structure [8]

The reduction of strength on different regions of bridge structure made of stone was mitigated with the use of cement. As per the intended function of bridge different designs of bridge were constructed. These designs were based on various considerations like terrain type, material of bridge and budget of bridge.

2. LITERATURE REVIEW

Jeong-Tae Kim et. al. [1] have conducted research on damage detection of bridge structure using vibration response monitoring. From the vibration amplitude the accurate location of damage, severity of damage and effect of temperature were investigated.

Brownjohn et al [2] have conducted research on vibration analysis of Humber Bridge located at Hong Kong. The damage detection was done using "Natural Excitation Technique/Eigensystem Realization Algorithm, Stochastic Subspace Identification, and the Poly-Least Squares Frequency Domain method" [2]. The research findings have shown the viability of these techniques for crack identification and monitoring.

Whelan et. al. [3] have conducted research on health monitoring of bridge structures. The health monitoring systems involves use of sensors for crack detection. The study found that the "use of stochastic SSI subspace identification techniques to approximate modal parameters from only output experimental data was found to be preferable to the frequency domain decomposition FDD method despite the increased computational effort and subjectivity required to recognize the system poles" [3].

Wardhana and Hadipriono et. al. [4] have conducted research on damage of bridge structure due to various environmental and operational factors. The environmental factors investigated are abrasion, corrosion and operational factors considered are overloading. From the research it was found that major reason for collapse of bridge was overloading which accounted for more than 73% of total cases.

3. OBJECTIVES

The objective of current research is to investigate the vibration characteristics of bridge structure using different materials. The modal analysis of bridge structure is conducted using ANSYS simulation package. The materials investigated in the research is concrete material, silicone rubber and neoprene rubber. The mode shapes, natural frequency and mass participation factor is evaluated for different bridge materials.

4. METHODOLOGY

The FEA model analysis is conducted on bridge structure to determine natural frequency and mode shape for 1st, 2nd and 3rd natural frequencies. The analysis involves different stages.

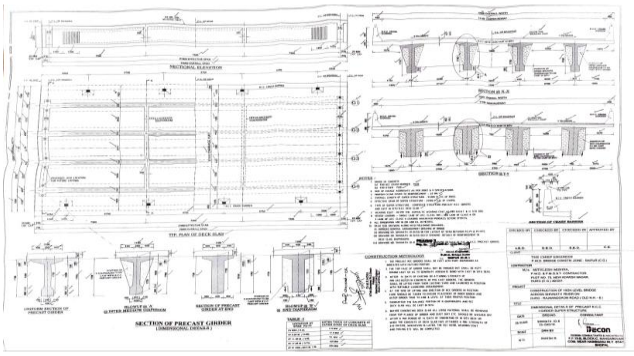

Figure 2: Schematic of bridge structure

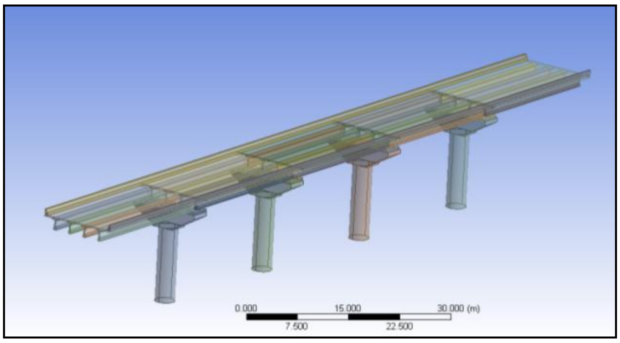

Figure 3: Imported model of bridge structure

The bridge structure is developed as per schematic shown in figure 2. The bridge structure model is checked for geometric errors and surface patches. The developed model of bridge structure is shown in figure 3 above.

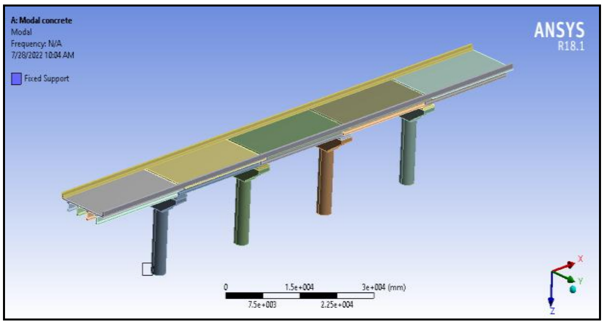

Figure 4: Loads and boundary condition for modal analysis

The boundary conditions are applied on the structure for modal analysis. Under modal analysis, the base of the structure is applied with fixed support. The FEA simulation is run using sparse matrix solver and number of iterations are carried out.

5. RESULTS AND DISCUSSION

From the FEA analysis the natural frequency, mode shape and mass participation factor is obtained for concrete material, silicone rubber and neoprene rubber material.

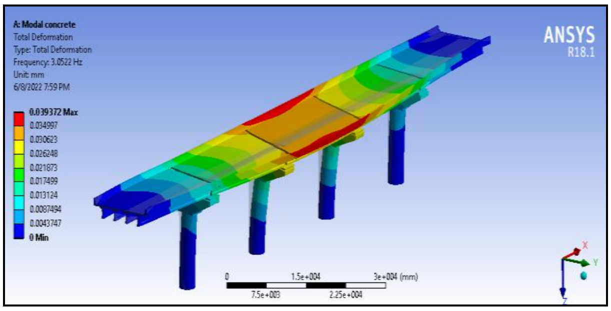

Figure 5: 1st frequency mode shape for concrete

For concrete material bridge deck and 1st natural frequency mode shape, the maximum deformation is observed at the bridge crash barrier zone where in the magnitude of deformation is .039mm.

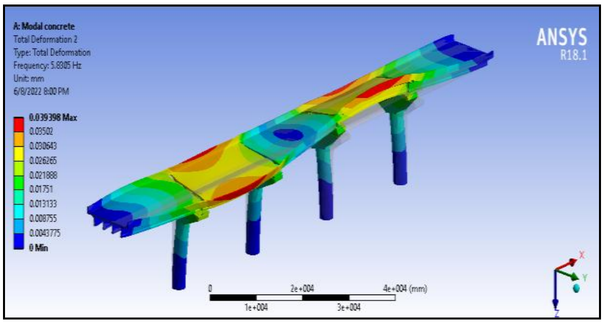

Figure 6: 2nd frequency mode shape for concrete

For concrete material bridge deck and 2nd natural frequency mode shape, the maximum deformation is observed at the bridge crash barrier zone where in the magnitude of deformation is .0393mm.

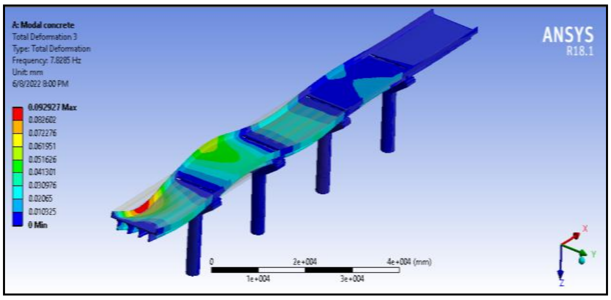

Figure 7: 3rd frequency mode shape for concrete

For concrete material bridge deck and 3rd natural frequency mode shape, the maximum deformation is observed at the bridge crash barrier zone where in the magnitude of deformation is .092mm.

Table 1: Mass participation factor for concrete material

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*****  PARTICIPATION  FACTOR  CALCULATION  *****  Y
DIRECTION
                                    CUMULATIVE   RATIO
EFF.MASS
 MODE  FREQUENCY    PERIOD    PARTIC.FACTOR   RATIO
EFFECTIVE  MASS    MASS  FRACTION    TO  TOTAL  MASS
   1   3.05217    0.32764     42.967     1.000000   1846.12
0.955685                                            0.572179
     2     5.83046        0.17151      -0.42157        0.009812
0.177720               0.955777                   0.550817E-04
     3     7.82853        0.12774      -0.48238        0.011227
0.232689               0.955897                   0.721186E-04
     4      8.17151       0.12238        0.51682        0.012028
0.267100               0.956036                   0.827837E-04
   5   8.63898    0.11575     4.7948     0.111593   22.9899
0.967937                                          0.712539E-02
   6   8.78618    0.11382     7.8700    0.183166   61.9370
1.00000                                           0.191965E-01
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      sum                                  1931.73
0.598710
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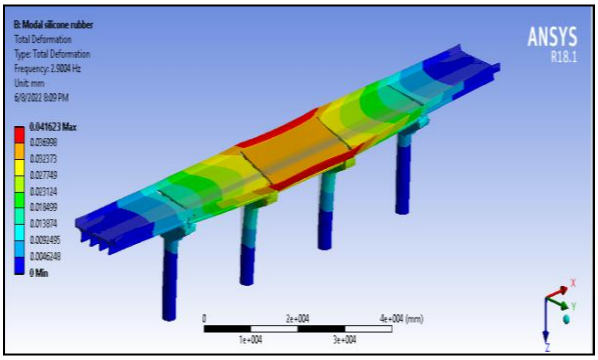

Figure 8: 1st frequency mode shape for silicone rubber

For silicone rubber material bridge deck and 1st natural frequency mode shape, the maximum deformation is observed at the bridge crash barrier zone where in the magnitude of deformation is .041mm.

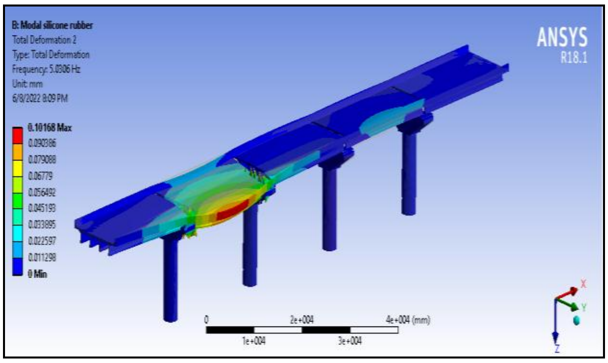

Figure 9: 2nd frequency mode shape for silicone rubber

For silicone rubber material bridge deck and 2nd natural frequency mode shape, the maximum deformation is observed at the bridge crash barrier zone where in the magnitude of deformation is .101mm.

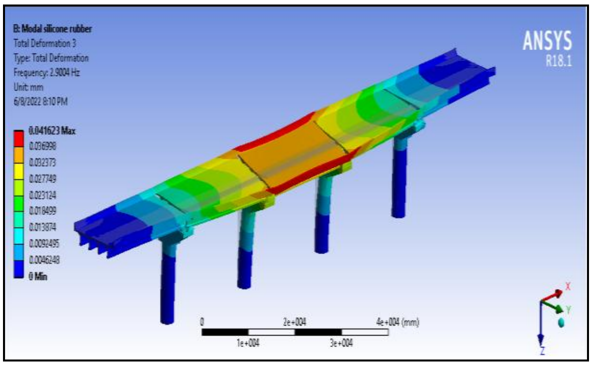

Figure 10: 3rd frequency mode shape for silicone rubber

For silicone rubber material bridge deck and 3rd natural frequency mode shape, the maximum deformation is observed at the bridge crash barrier zone where in the magnitude of deformation is .041mm.

Table 2: Mass participation factor for silicone material

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 ***** PARTICIPATION FACTOR CALCULATION ***** Y  DIRECTION
                                       CUMULATIVE      RATIO
EFF.MASS
  MODE    FREQUENCY      PERIOD      PARTIC.FACTOR      RATIO
EFFECTIVE      MASS       MASS     FRACTION       TO    TOTAL     MASS
    1      2.90045       0.34477       41.445       1.000000     1717.68
0.919134                                                      0.536681
    2      5.03064       0.19878       -4.6726      0.112744     21.8336
0.930818                                                 0.682180E-02
    3      5.27097       0.18972       6.1424       0.148205     37.7285
0.951006                                                 0.117881E-01
    4      5.33261       0.18753       -9.1381      0.220489     83.5053
0.995690                                                 0.260908E-01
    5      5.49448       0.18200       2.7555       0.066487     7.59301
0.999753                                                 0.237240E-02
   6     5.53050      0.18082     -0.67921      0.016388   0.461326
1.00000                                                  0.144139E-03
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  sum                                     1868.80              0.583898
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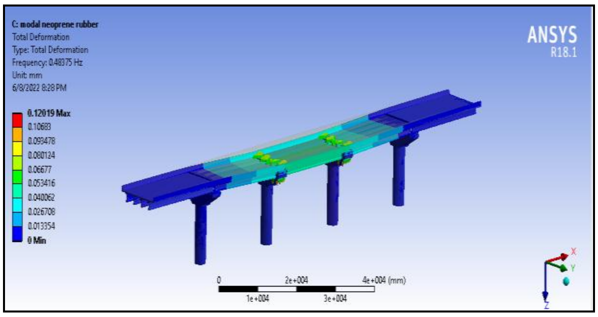

Figure 11: 1st frequency mode shape for neoprene rubber

For neoprene rubber material bridge deck and 1st natural frequency mode shape, the maximum deformation is observed at the bearing zone where in the magnitude of deformation is .12 mm.

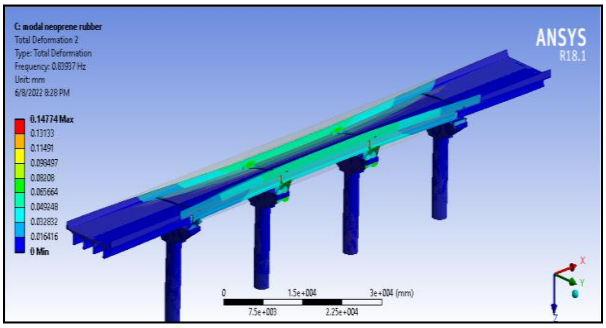

Figure 12: 2nd frequency mode shape for neoprene rubber

For neoprene rubber material bridge deck and 2nd natural frequency mode shape, the maximum deformation is observed at the bearing zone where in the magnitude of deformation is .147 mm.

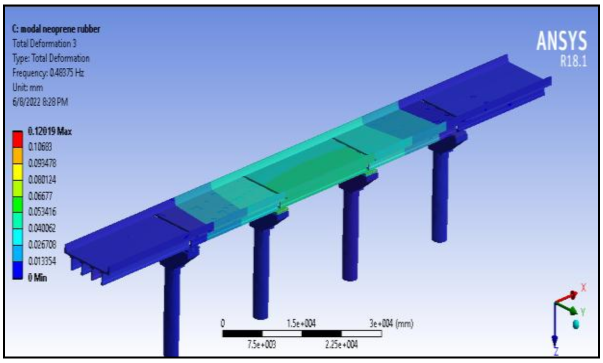

Figure 13: 3rd frequency mode shape for neoprene rubber

For neoprene rubber material bridge deck and 3rd natural frequency mode shape, the maximum deformation is observed at the bearing zone where in the magnitude of deformation is .1201 mm.

Table 3: Mass participation factor for Neoprene material

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***** PARTICIPATION FACTOR CALCULATION ***** Z DIRECTION
                                      CUMULATIVE      RATIO
EFF.MASS
  MODE   FREQUENCY      PERIOD      PARTIC.FACTOR     RATIO
EFFECTIVE    MASS     MASS    FRACTION     TO    TOTAL    MASS
    1    0.483751      2.0672       31.109      1.000000     967.775
0.999139                                                    0.302071
    2    0.839370      1.1914      0.90011      0.028934    0.810205
0.999976                                                 0.252888E-03
    3    0.938499     1.0655    0.83937E-01   0.002698   0.704539E-
02                      0.999983                         0.219907E-05
    4     1.21398     0.82374    -0.98624E-01   0.003170   0.972664E-
02                      0.999993                         0.303597E-05
    5     1.23503     0.80970    -0.67078E-01   0.002156   0.449952E-
02                        0.999998                        0.140443E-05
    6    1.24749      0.80161    -0.45203E-01   0.001453   0.204334E-
02                        1.00000                         0.637787E-06
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  sum                                         968.609             .302331
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6. CONCLUSION

The FEA is a viable tool in evaluating the vibration characteristics of bridge structure. From the modal analysis, the natural frequencies and mode shapes are evaluated for bridge with concrete, silicone rubber and neoprene rubber material.

1. From the modal analysis, the critical regions of high deformation are identified.

2. From modal analysis of concrete material, the critical region is found to be at crash barrier which exhibited maximum deformation and susceptible to amplitude build up during resonance.

3. From modal analysis of silicone rubber material, the critical region is found to be at crash barrier which exhibited maximum deformation and susceptible to amplitude build up during resonance.

4. From modal analysis of neoprene rubber material, the maximum deformation is observed to be at bearing region whereas the bridge structure and crash barrier have lower deformation.

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