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EFFECT OF DIFFERENT TEST FIXTURE VARIABLES ON THE AFTER-TREATMENT SYSTEM DYNAMICS

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Abstract — *This paper covers the basic idea of using the test fixtures for vibration analysis and the effect of different design variables on the dynamics of After-treatment system. Vibration Test Fixtures are the indispensable part in the manufacturing industry. The vibration testing poses a challenge to design good vibration test fixture. Thus, to design the fixture design guidelines; effect of design parameters are need to be studied. In present work, four cases are studied for four different parameters. These parameters are material, fixing location, geometry and when fixture is replaced with bracket. To study the effect of these parameters on the After-treatment system dynamics, we performed modal and PSD analysis and compared the results with existing conditions.*

Keywords- *After-treatment system, modal Analysis, random vibration analysis, vibration, vibration test fixtures.*

I. INTRODUCTION

The automobile has come to symbolize the essence of a modern industrial society. Automotive components are subjected to rigorous testing before they can be certified ready for production. On many components, that testing includes random vibration excitation in order to simulate a broad range of vibration encountered in the actual application. But in actual practice, it is not possible to get best solution. The possible reasons for not getting best results may be a lot of uncertainties and vague assumptions made in analysis process.

Vibration Test Fixtures are the indispensable part in the manufacturing industry. The vibration testing poses a challenge to design good vibration test fixture. The off-highway and on-highway heavy duty vehicles are subjected to large number of forces like vibrations which are highly random in nature. These vibrations are the most important mode of failure in After-treatment system. After-treatment system is the emission control device which helps to reduce the environmental pollution causing due to automobile emission. To qualify or verify the acceptability of After-treatment system for certain environment, vibration testing is done. As After-treatment system cannot be placed directly on the shock testing machine (Shaker table), thus the vibration test fixture acts as interface between the system and the machine. Shaker table is used to generate an input spectrum such as forces or accelerations that mimics real working conditions as much as possible. The purpose of test fixtures is to couple mechanical energy from a shaker table into a test specimen.

In real environment these random vibrations are transferred on to the brackets, used to mount the After-treatment system. The uncertainties in mechanical properties, tolerances in fabrication and assembly processes of Fixture and Bracket may cause differences in their results. Hence, the system dynamics varies for testing with actual bracket and testing with fixture.

II. MODAL ANALYSIS OF FIXTURE WITH AFTER-TREATMENT SYSTEM

Modal analysis provides the natural frequencies and mode shapes of the system. This information is used to compare the different models to determine impact of Mass Participation Factor. For performing modal analysis of fixture and mounting bracket with the After-treatment system certain boundary conditions are applied, such as

(i) Maximum modes to find: 50
(ii) Frequency range minimum: 10 Hz
(iii) Frequency range maximum: 1000 Hz

Here, we have recorded the global mode shapes in all six directions i.e. Axial (X), Vertical (Y), Lateral (Z), Rotational axial, Rotational vertical and Rotational lateral direction.

Figure 1. Experimental Test Fixture Set up with After-treatment System

<u>CASE 1:</u> Comparison between After-treatment System 1 with Old Aluminum fixture and Structural steel fixture

In this case, we have taken AT system 1 with old fixture as configuration 1. Here we have changed material of vibration test fixture from Aluminum to Structural steel.

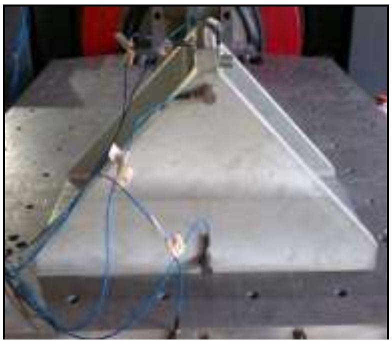

Figure 2. Configuration 1: AT system 1 with Old Fixture

Here, we have considered material as a varying parameter and keeping geometry and fixed support constant. Mode shapes and natural frequencies are recorded below. From this, we can say that on changing material of fixture from Aluminum to Structural Steel there is considerable increase in its natural frequency.

Table 1. Natural Frequency for Materials

MODE SHAPES	ALUMINUM FIXTURE	STRUCTURAL STEEL FIXTURE
1	84.85 Hz	93.495 Hz
2	91.65 Hz	96.875 Hz
20	161.88 Hz	164.725 Hz
22	170.98 Hz	171.375 Hz

Further, we have recorded Mass Participation Factor to study its effect. Hence, we got the following results:

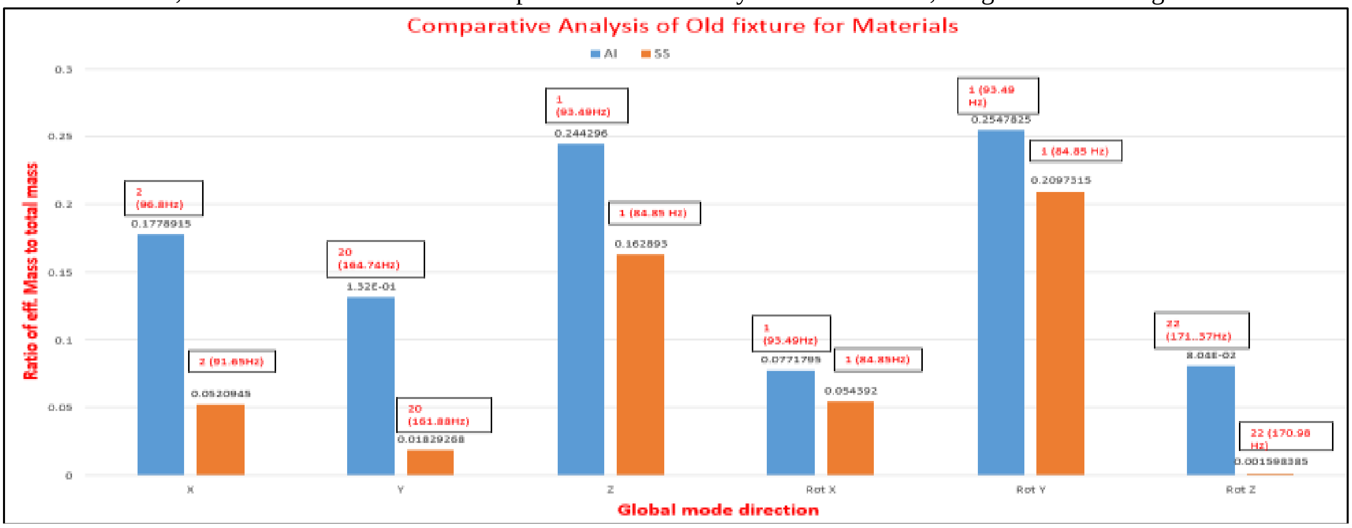

Figure 3. Comparative Analysis of old Fixture for materials

Observation

(i) From the above graph, it is observed that on changing material from Aluminum to Steel Natural Frequency is increasing in the range of 0.23% to 10.18%.

(ii) It is also observed that on changing material from Aluminum to Steel Mass Participation Factor of system reduces in the range of 17% to 98%.

CASE 2: Comparison between Analysis Vs Actual testbolt fixing location effect on After-treatment 1 dynamics with old Aluminum Fixture

In this case, we have considered configuration 1 as case 1 but changed the number of fixed bolts of fixture on the shaker table.

Here, we have considered fixing bolt location as a varying parameter and keeping geometry and material of the system constant. Mode shapes and natural frequencies are recorded below. From this, we can say that on changing the fixed support by changing fixing location of fixture bolts on shaker table there is considerable decrease in its natural frequency.

Table 2. Natural Frequency for changing Fixing Location

MODE SHAPES	ALL FIXED (Analytical Condition)	ACTUAL FIXING LOCATION (Testing Condition)
1	88.805 Hz	84.85 Hz
2	92.245 Hz	91.65 Hz
20	164.735 Hz	161.88 Hz
22	173.435 Hz	170.98 Hz

Further, we have recorded Mass Participation Factor to study its effect. Hence, we got the following results:

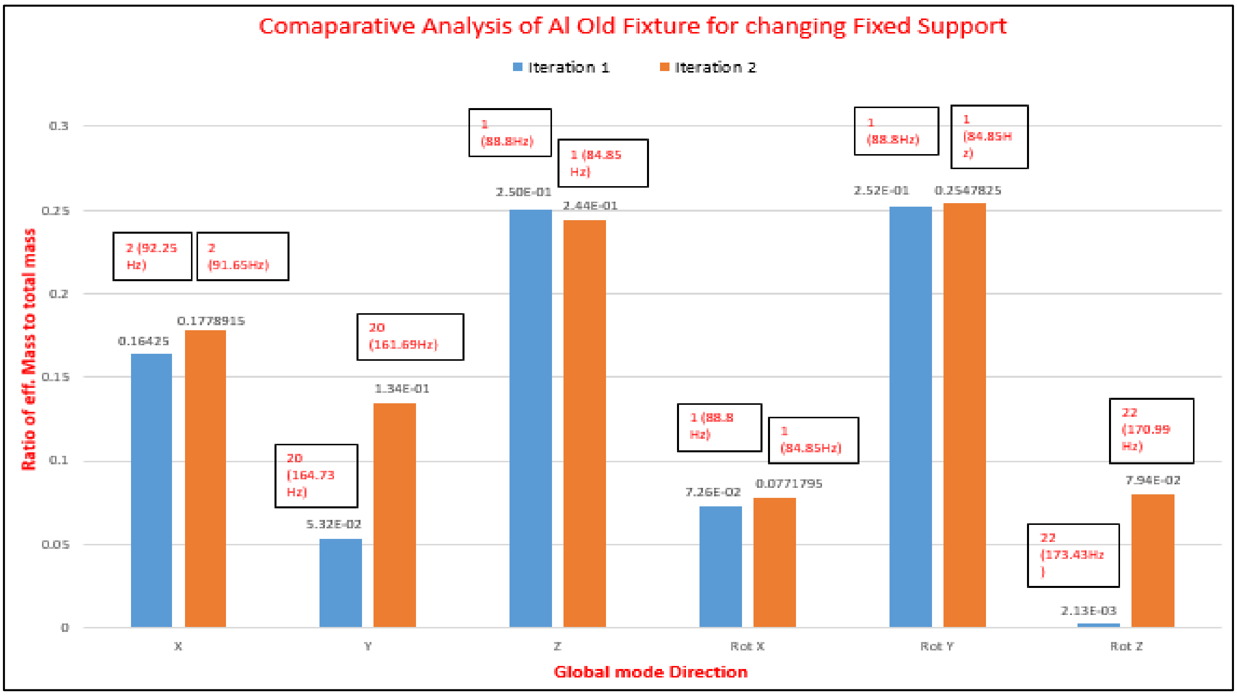

Figure 4. Comparative Analysis of old Fixture for fixed supports

Observation

(i) From the above graph, it is observed that on changing fixing location from analysis to actual condition Natural Frequency is decreasing in the range of 0.65% to 4.44%.

(ii) It is also observed that on changing fixing location from analysis to actual condition Mass participation factor increases.

<u>CASE 3:</u> Comparison between old and New Fixture for actual fixed support for After- treatment system 1

In this case, two configurations are used for comparison by changing geometry of fixture.

Figure 5. Configuration 1: AT system 1 with Old Fixture

Figure 6. Configuration 2: AT system 1 with New Fixture

Here, we have considered geometry of Fixture as varying parameter and keeping material and fixed support of the system constant. Mode shapes and natural frequencies are recorded below. From this, we can say that on changing geometry of the Fixture by changing design and increasing its stiffness by increasing the width of a rib there is considerable decrease in its natural frequency.

Table 3. Natural Frequency for Geometry change

MODE SHAPES	OLD FIXTURE	NEW FIXTURE
1	75.215 Hz	83.615 Hz
2	79.255 Hz	86.59 Hz
4	108.12 Hz	113.21 Hz
19	154.645 Hz	164.785 Hz

Further, we have recorded Mass Participation Factor to study its effect. Hence, we got the following results:

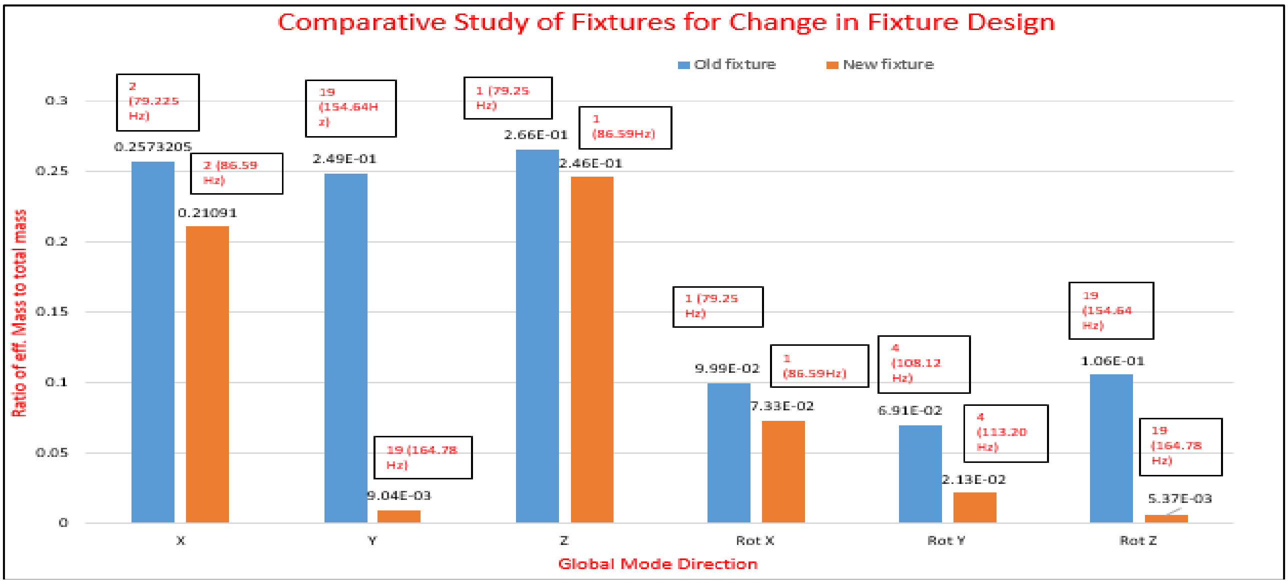

Figure 7. Comparative Analysis for Geometry change

Observation

(i) From the above graph, it is observed that on changing geometry of fixture from old to new fixture Natural Frequency is increasing i.e. from 79.25 Hz to 86.59 Hz because the thickness of vertical supports has increased from 11.43 to 12.7 mm.

(ii) It is also observed that on changing geometry of fixture from uncut to cut fixture Mass participation factor decreases.

CASE 4: Comparative study of After-treatment system2 with Guillotine Fixture and OEM Bracket

In this case, two configurations are used with AT system 2. First, AT system 2 with guillotine fixture and second AT system with OEM mounting bracket.

Figure 8. AT system 2 with Fixture and OEM mounting Bracket

Here, we have considered actual testing condition of After-treatment system 2 with Fixture and Bracket. Mode shapes and natural frequencies are recorded below for the same. From this, we can say that on changing fixture by bracket there is considerable decrease in its natural frequency.

Table 4. Natural Frequency of Fixture and Bracket

MODE	MODE SHAPE (Fixture)	MODE SHAPE (Bracket)	NATURAL FREQUENCY (Fixture)	NATURAL FREQUENCY (Bracket)
Axial	31	2	145.01	32.305
Vertical	100	10	244.11	75.305
Lateral	8	1	79.47	30.215
Rot axial	17	1	108.82	30.215
Rot vertical	18	3	111.27	48.63
Rot lateral	100	2	244.11	32.305

Further, we have recorded Mass Participation Factor to study its effect. Hence, we got the following results:

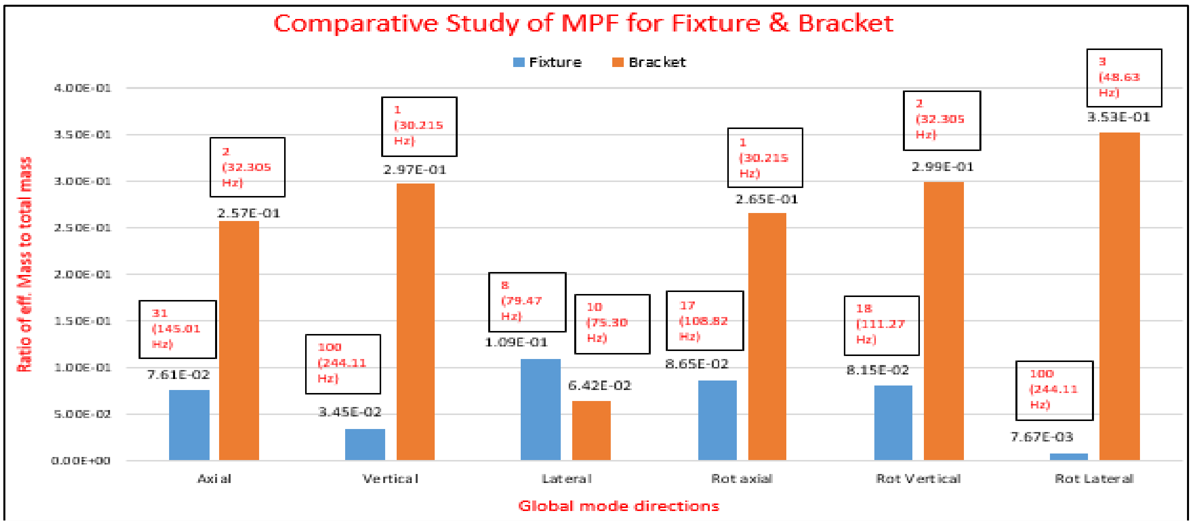

Figure 9. Comparative Analysis for Fixture & Bracket

Observation

(i) From the above graph, it is observed that by replacing fixture with bracket there is a drastic decrease in Natural Frequency for same mode shape.

(ii) It is also observed that by replacing fixture with bracket Mass participation factor increases.

III. PSD ANALYSIS OF FIXTURE WITH AFTER-TREATMENT SYSTEM

The entire After-treatment system is subjected to PSD input profile for 10 hours. To evaluate equivalent stresses we have considered various locations in three directions i.e. Axial (X), Vertical (Y) and Lateral (Z) directions. Here we have recorded Equivalent von-mises stress, damage and the damaging peak frequency with the help of Dirlik script which uses Miner's rule.

<u>CASE 1:</u> Comparison between After-treatment System 1 with Old Aluminum fixture and Structural steel fixture

A. From the figure 3.1, we have observed that on changing the material from Aluminum to Steel:
   (i) Stress has reduced in the range of 7% to 26%.
   (ii) Damage has reduced in the range of 28% to 84%.

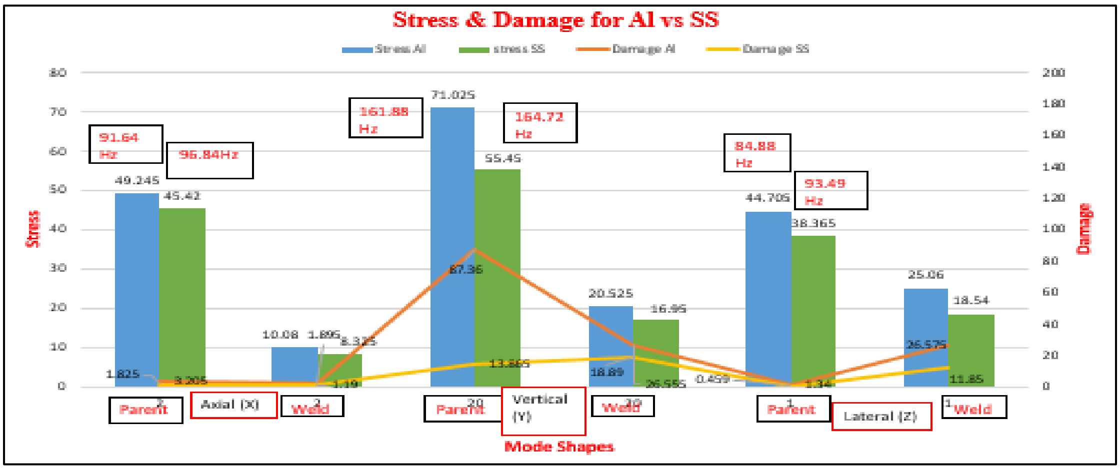

Figure 10 Comparison of Stress & Damage for Al vs. SS

Plots of Dirlik Script

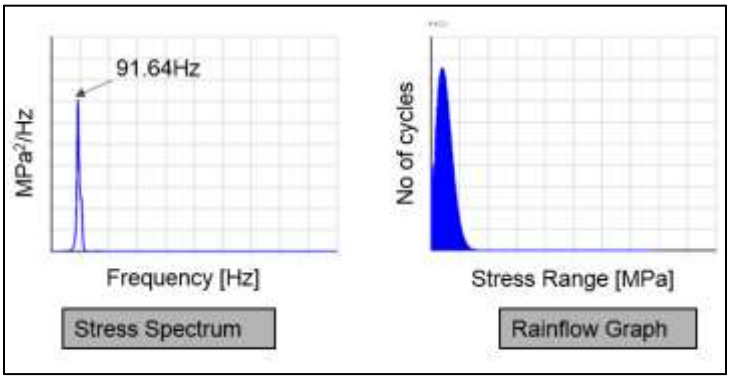

Figure 11. Dirlik plot for parent material - Al 91.64 Hz

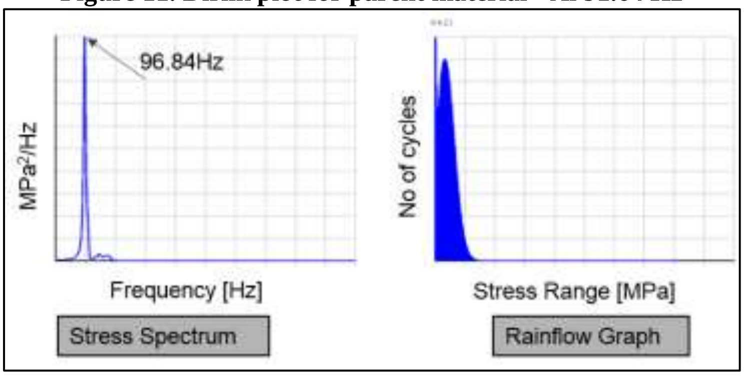

Figure 12. Dirlik plot for parent material - SS 96.84 Hz

B. From the analysis it is highly evident that the cumulative damage is high for the Aluminum material as compared to Structural Steel.

<u>CASE 2:</u> Comparison between Analysis Vs Actual testbolt fixing location effect on After-treatment 1 dynamics with old Aluminum Fixture

C. From the figure 3.4, we have observed that on changing the Fixing location from Analysis condition to actual testing condition

(i) Stress decreases in the range of 1% to 11% in vertical & lateral direction (except in axial direction)
(ii) Damage increased with increase in mass participation factor in axial and lateral direction, but in vertical it reduced. The range of change in damage is 5% to 66% due change in fixing location.

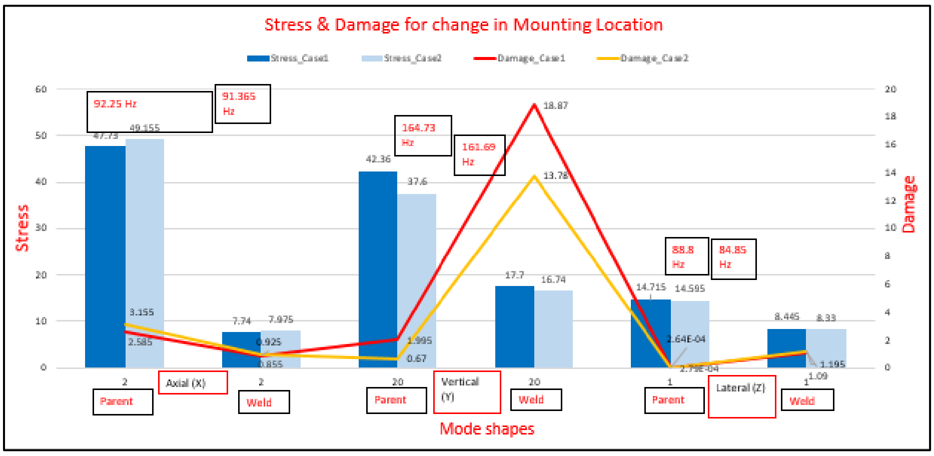

Figure 13. Comparison of Stress & Damage for change in Fixed Support

Plots of Dirlik Script

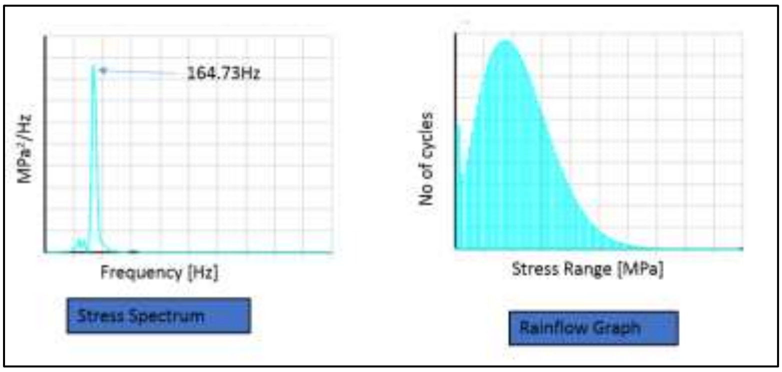

Figure 14. Dirlik plot for weld material – All fixed 164.73 Hz

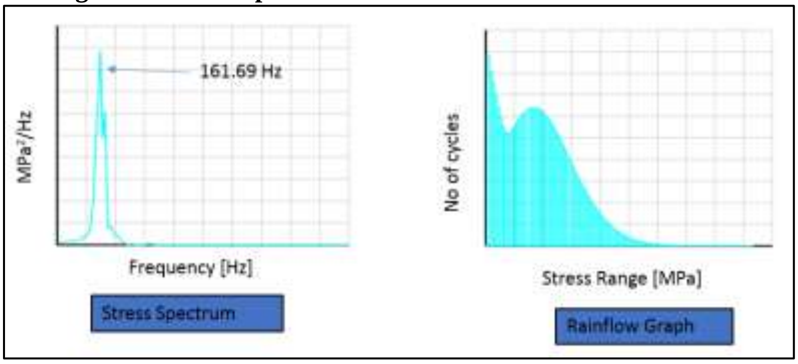

Figure 15. Dirlik plot for weld material – Actual fixed 161.69 Hz

D. From the analysis it is highly evident that the cumulative damage is high for the actual fixed mounting location than all fixed mounting location.

<u>CASE 3:</u> Comparison between old and New Fixture for actual fixed support for After- treatment system 1

E. From the figure 3.7, we have observed that on changing the geometry from old fixture to new fixture

(i) Stress increases in the range of 5% to 19% in axial & lateral direction (except in vertical direction)

(ii) Damage increases in the range of 64% to 355% in axial & lateral direction (except in vertical direction)

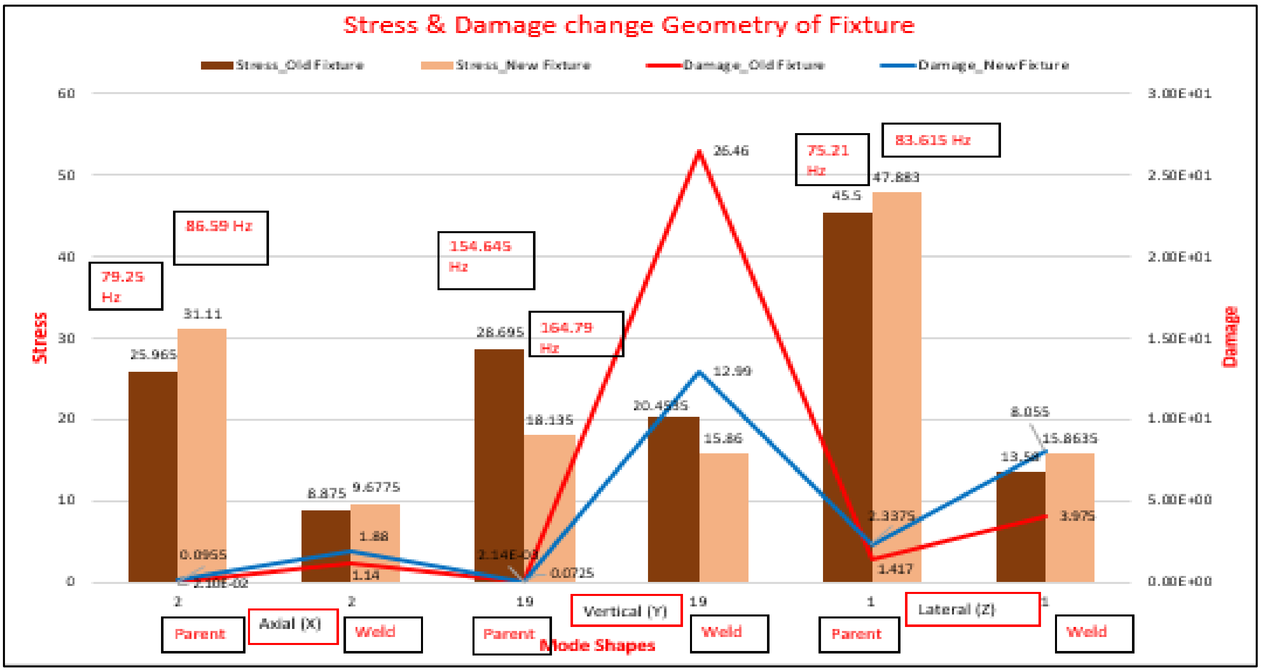

Figure 16. Comparison of Stress & Damage for Geometry change

Plots of Dirlik Script

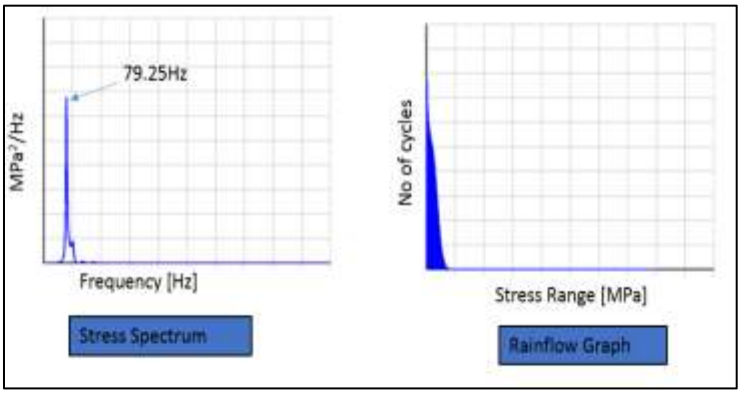

Figure 17. Dirlik plot for parent material - Old 79.25 Hz

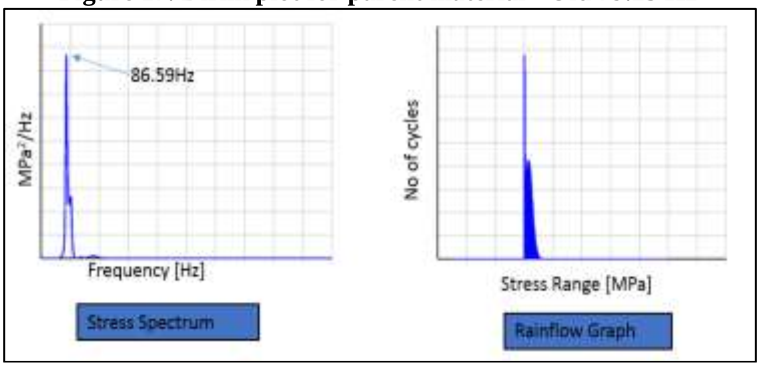

Figure 18. Dirlik plot for parent material – New 86.59 Hz

F. From the analysis it is highly evident that the cumulative damage is high for the New Fixture than the Old Fixture.

<u>CASE 4:</u> Comparative study of After-treatment system2 with Guillotine Fixture and OEM Bracket

G. From the figure 3.10, we have observed that on changing Fixture by Bracket:

(i) Stress increases in the range of 22% to 100% in all three directions.

(ii) Damage increases in the range of 29% and higher in all three directions.

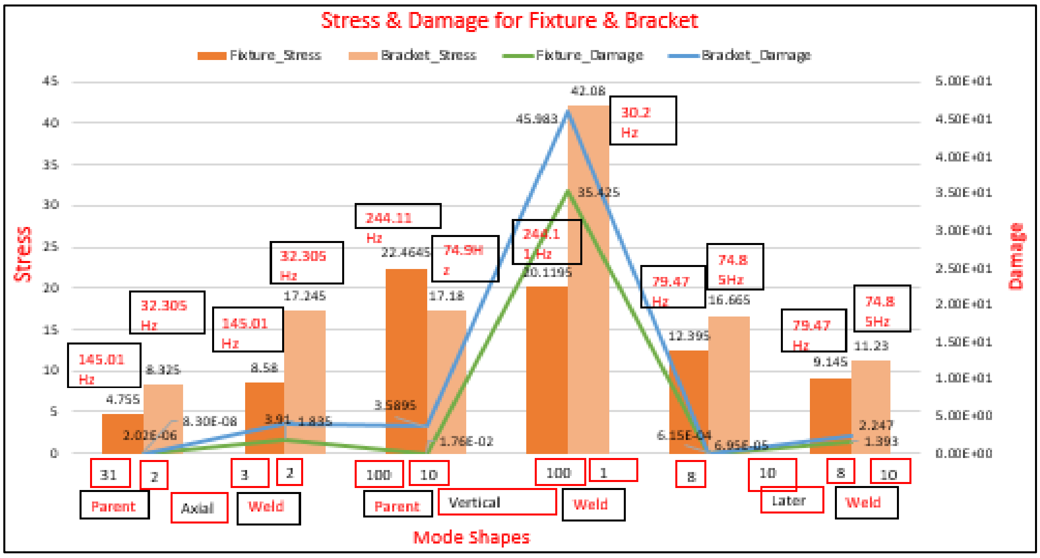

Figure 19. Comparison of Stress & Damage for Fixture & Bracket

Plots of Dirlik Script

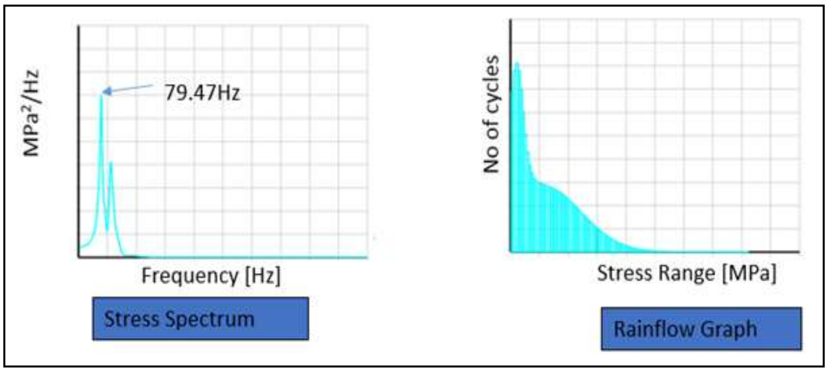

Figure 20. Dirlik plot for weld - Fixture 79.47 Hz

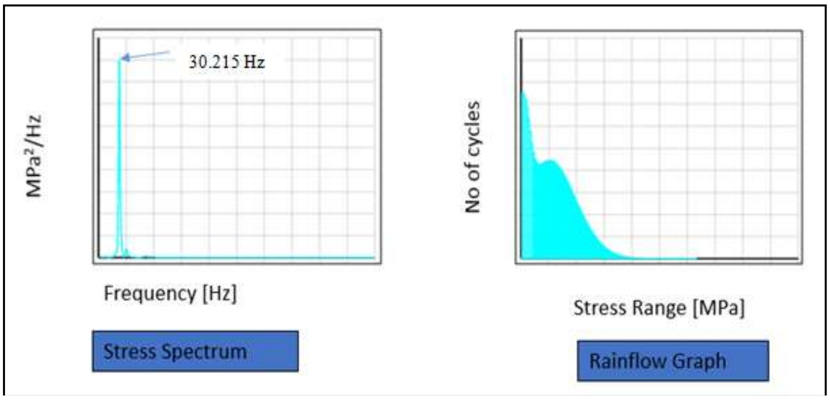

Figure 21. Dirlik plot for weld – Bracket 30.215 Hz

H. From the analysis it is highly evident that the cumulative damage is high for the Fixture than the Mounting Bracket.

IV. CONCLUSION

Based on the above research and case studies we have drawn following conclusions which fulfill the objective of our research.

CASE 1:

On changing material of fixture from Aluminum to Structural steel, we reached on conclusion that mass participation factor of the system decreases which will also reduce the damage of the complete structure. But, this will increase the overall weight of system which is not feasible . The change in damage has been observed in the range of 28% to 65% due to fixture material change.

CASE 2:

On changing fixing locations and reducing number of bolts from analysis to actual testing condition of fixture to shaker table, we can say that,the frequency of system reduces also the mass participation factor of the system modes increases which will also increase the damage of the complete structure. So, in analysis and test same number of bolts and locations should be fixed. The change in damage has been observed in the range of 5% to 66% due to change in bolt location of fixture on shaker table.

CASE 3:

On changing geometry of fixture from old to new fixture, we reached on conclusion that mass participation factor of the system has decreased and the damage of the system has increased. The change in damage has been observed in the range of 55 to 355% due to fixture geometry change.

CASE 4:

On changing fixture by bracket the frequencies of the system reduce, also increases the mass participation factor of system modes which will also increases the damage of complete system. The change in damage has been observed in the range of 29% and above.

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