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# COMPARISON OF FE AND MODAL MODELS IN MODEL UPDATING METHODS

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**Abstract**

One of the most important applications of modal testing is the validation of the analytical model of dynamic structures by comparing the experimentally driven modal parameters with those of analytical models. Once the analytical model is validated, it can be used with confidence for further analysis such as response prediction, structural coupling, stress analysis, life time prediction, etc.

In this article, the dynamic properties of a steel plate and a 3D steel frame are investigated using the theoretical method of Finite Element Method (FEM) and the experimental method of Modal Testing. Finite Element Analysis is used to determine the best accelerometer locations and the suitable frequency range in order to conduct Modal Testing. A 24-channel spectrum analyzer is used to derive the natural frequencies, mode shapes and damping ratios from Frequency Response Functions (FRFs). Finally, the dynamic properties obtained from Modal Testing are compared with those of the Finite Element Method (FEM). The mass and stiffness error matrices are calculated. It is shown that the dynamic behaviour of the new model and the experimental one are close together although the error can not be exactly located in the models. Based on this study some remarks are pointed out in using model updating methods.

## 1. INTRODUCTION

FE modelling has become the most popular technique in structural dynamic analysis. However, the dynamic responses obtained from FE analysis are seldom in perfect agreement with modal testing results. Therefore a model updating procedure should be introduced in order to adjust the analytical model so that the analysis and test results agree, and so that a valid model is available for design calculations. However, neither Finite Element model nor Modal Testing model can be assumed to be perfect, but both have features which can be combined to give a more accurate description of the dynamics of structure.

Because of the different limitations and assumptions implicit in the two approaches, the FE model and experimental modal model have different characteristics and different advantages and drawbacks. The FE model generally has a large number of coordinates so that the vibration characteristics can be described in detail and can cover a comparatively wide frequency range. However, due to insufficient or incorrect modeling, geometrical over-simplification and uncertainties on the element properties (especially the properties of joints which have not been fully explored), the FE model may well be inaccurate or even incorrect. In contrast, the experimental data or experimentally-derived modal properties are generally considered to be ‘correct’ or at least close to the true representation of the structure, because modal testing deals with the actual structure rather than an idealization. However, due to the limited number of coordinates and modes which can be included (because of various restrictions in measurement), the information thus obtained is available primarily as selected modal parameters, rather than the full spatial properties as provided by the FE model.

The principle of correlating the models derived from these two different approaches is to make use of the advantages of both and to overcome their disadvantages. Basically, it is believed that more confidence can be placed in the experimental modal data than in the FE model. Therefore, model updating schemes have been developed which aim to improve or to correct the initial FE model using modal test results [1].

This article considers two different case studies in order to locate the errors in Finite Element or Modal models.

## 2. CASE STUDIES

### 2.1 Finite Element models

A Plate and a 3D frame are selected as applications. The plate is from steel and has 30cm length, 20cm width and 2mm thickness. The 3D frame is from steel and has been made of two different profiles (Figure 1). The Finite Element models of the steel plate and 3D steel frame are given in Figures 2 and 3. The steel plate was modelled by using 3D elastic shell element and the columns and beams of 3D steel frame were modelled by using 3D elastic beam element. The material and element types of the selected models are given in Table 1. The FINES program [2] was used for the theoretical solutions.

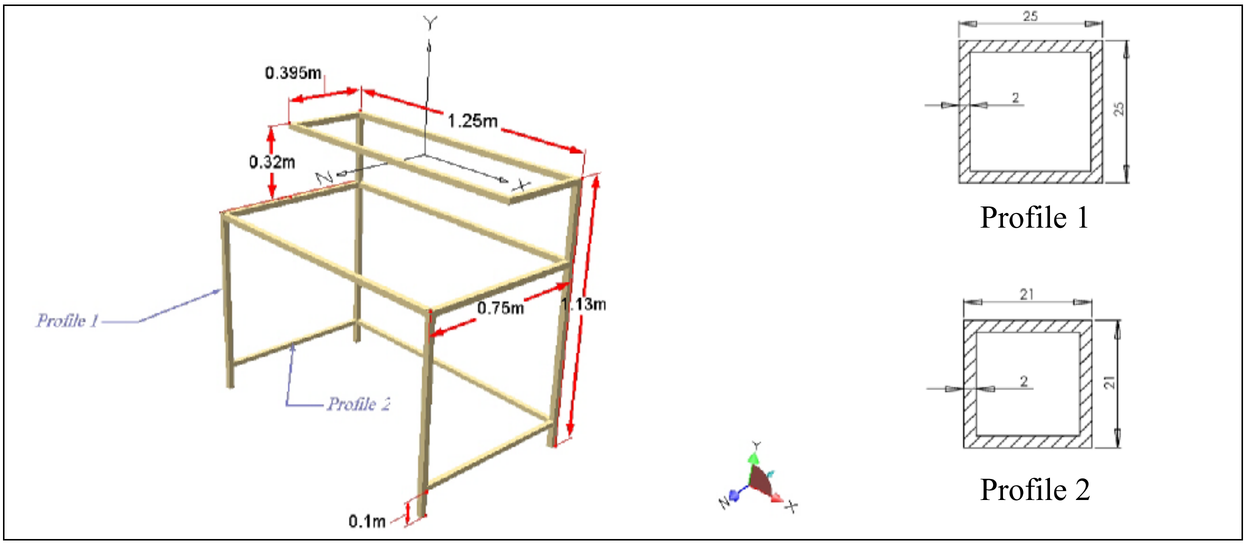


Figure 1. Dimensions of the 3D steel frame

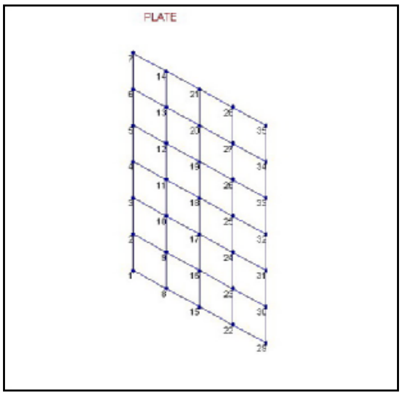


Figure 2. The FE model of steel plate.

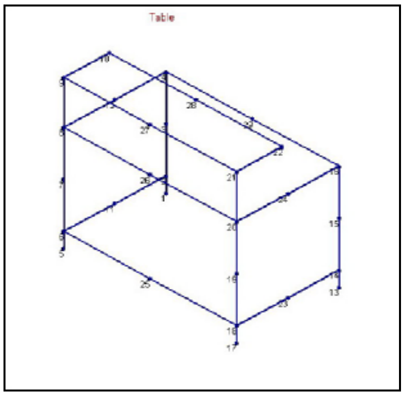


Figure 3. The FE model of 3D steel frame.

Table 1. Specifications of the models of steel plate and 3D steel frame

| | Steel Plate | 3D Steel Frame |
|---|---|---|
| Modulus of Elasticity ($N/m^2$) | 200E9 | 200E9 |
| Mass Density($kg/m^3$) | 7800 | 7800 |
| Poisson's ratio | 0.3 | 0.3 |
| Loss Factor[%] | 0.1 | 0.1 |
| Element Type | 3D Shell(3SHL04) | 3D Beam(3BEM02) |

### 2.2 Modal Models

The steel plate was suspended by soft springs to approximate the free-free condition (Figure 8). The test plan was carried out by MODPLAN software [2] and the optimum suspension, excitation and measurement points were found as shown in Figure 4, 5 and 6. Points 1, 4, 7, 15, 18, 21, 29, 32 and 35 were chosen as the measurement Degrees Of Freedom (DOFs). The selection of the measurement DOFs is based on the unique classification of the individual mode shapes to avoid spatial aliasing [3]. The corresponding AutoMAC matrix of the analytical mode shapes at the measurement DOFs is depicted in Figure 7. It can be seen that the overall spatial resolution is sufficient.

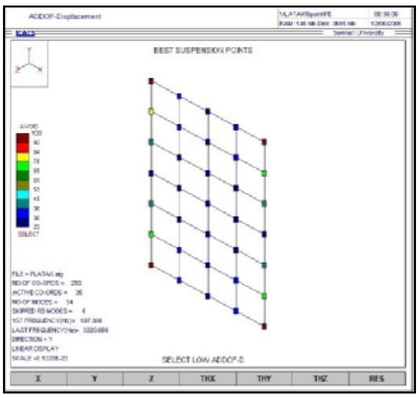

Figure 4. Best suspension points.

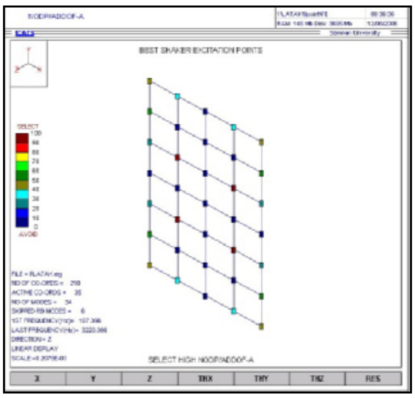

Figure 5. Best excitation points.

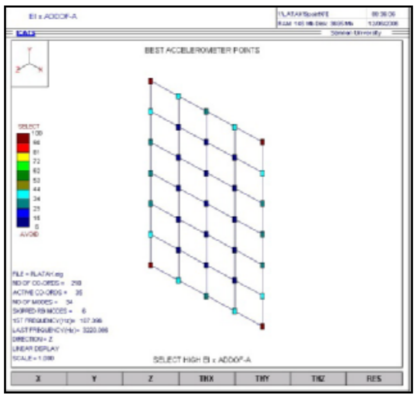

Figure 6. Best accelerometer points.

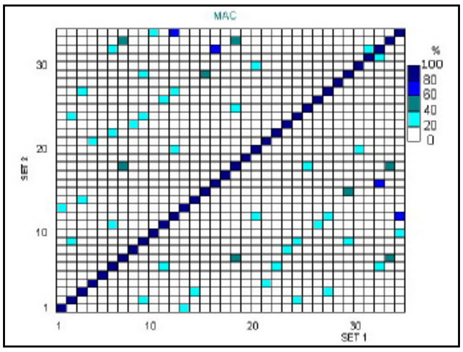


Figure 7. AutoMAC matrix of analytical mode shapes at measurement DOFs.

Figure 8. Modal test of steel plate.

The 3D frame was also suspended by soft springs to approximate the free-free condition (Figure 9). The measurement was carried out on 57 DOFs.

Figure 9. Modal test of 3D steel structure.

The excitation was carried out by a Brüel & Kjær 4808 shaker and the responses were measured using DJB accelerometers type A/120/VT. Force was measured using a Brüel & Kjær force transducer type 8200. The analysis was made using a Brüel & Kjær 24-channel spectrum analyzer system type 7536. The test equipment is shown in Figure 10.

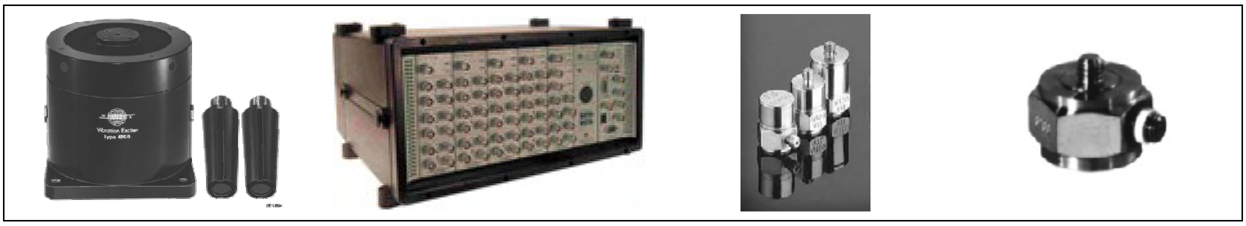

Figure 10. The test equipment (shaker, spectrum analyzer, accelerometers and force meter).

## 3. COMPARISON OF THEORETICAL AND EXPERIMENTAL MODELS

### 3.1 Steel plate

The first 6 natural frequencies of steel plate obtained from the Finite Element (FE) and Modal Testing are given in Table 2. It can be seen that there are some 10% error between the measured natural frequencies and the computed natural frequencies. As the transducers' weight is one-sixth of plate's weight, the mass loading effect of transducers caused this difference.

Table 2. The first 6 natural frequencies of steel plate.

| Mode | FE Analysis | Modal Testing | Error [%] |
|---|---|---|---|
| 1 | 106.7 | 94.9 | 12.4 |
| 2 | 217.5 | 198.8 | 9.4 |
| 3 | 254.5 | 230.5 | 10.4 |
| 4 | 450.8 | 388.1 | 16.2 |
| 5 | 583.9 | 522 | 11.9 |
| 6 | 646.5 | 570 | 13.4 |

The first 6 mode shapes of steel plate calculated from finite element and experimental modal analysis are plotted in Figure 11. The mode shapes calculated from theoretical analysis are similar to those of the experimental analysis.

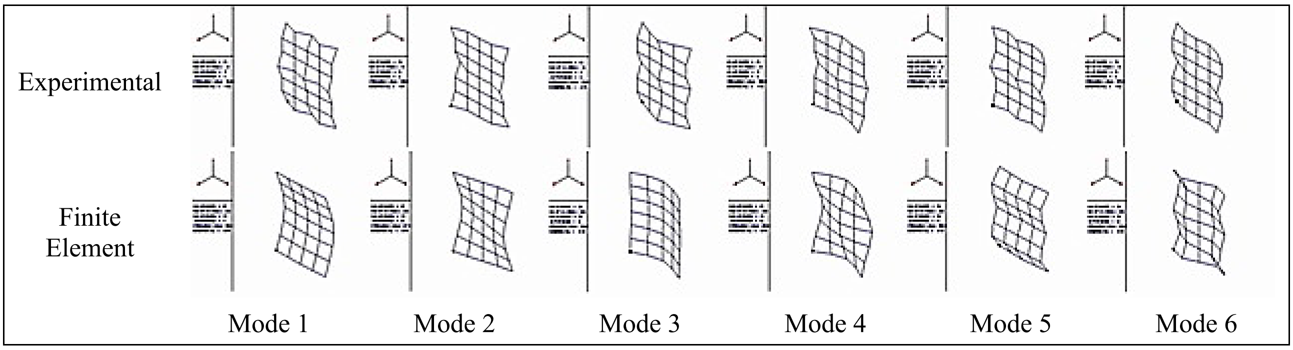


Figure 11. The first 6 mode shapes of steel plate.

The first 6 natural frequencies and mode shapes of steel plate from Finite Element and experimental Modal Analysis were used in Figures 12, 13, 14 and 15 in order to compare the compatibility of experimental and theoretical data. In these Figures SET 1 and SET 2 represent the experimental and theoretical data respectively.

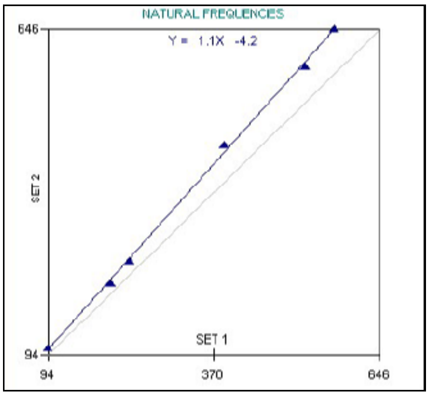


Figure 12. Natural frequency comparison.

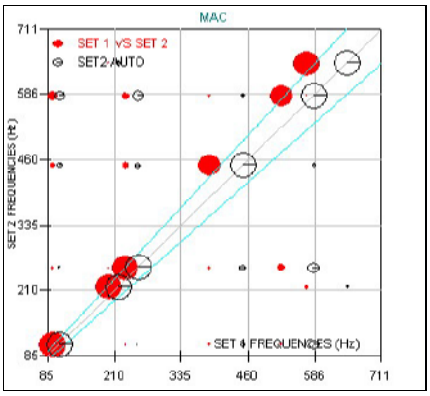


Figure 13. Frequency-scaled MAC (FMAC).

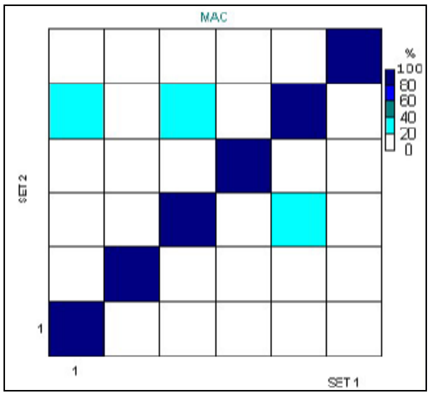


Figure 14. MAC.

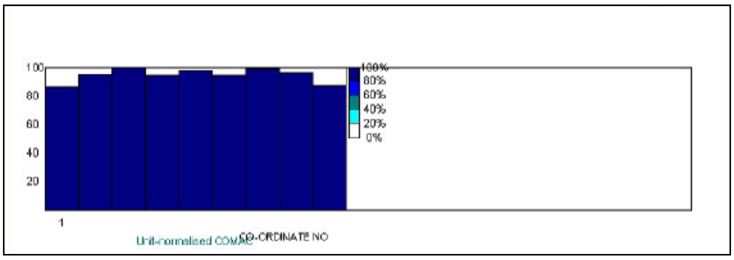


Figure 15. COMAC.

MODESH software [2] was used in order to calculate and plot mass and stiffness error matrices using modified error matrix method. Reduction technique was used to overcome the co-ordinates mismatch of two sets of data.

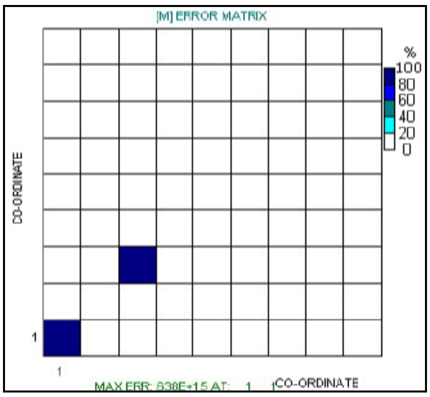


Figure 16. Mass error matrix.

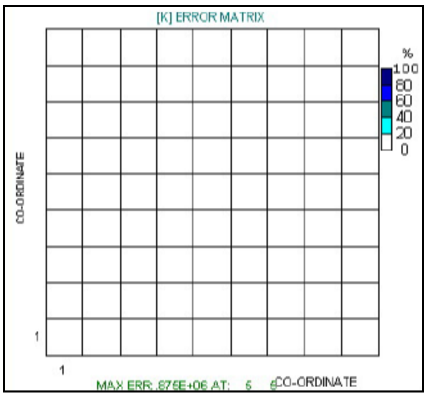


Figure 17. Stiffness error matrix.

### 3.2 3D steel frame

Table 3 shows the comparison of, the natural frequencies obtained from Modal Testing and Finite Element. In this case the results are closer together and the error is around 7%.

Table 3. The first 6 natural frequencies of 3D steel frame.

| Mode | FE Analysis | Modal Testing | Error [%] |
|---|---|---|---|
| 1 | 53.537 | 49.021 | 9.2 |
| 2 | 84.982 | 79.462 | 6.9 |
| 3 | 101.418 | 97.188 | 4.4 |
| 4 | 128.193 | 123.223 | 4 |
| 5 | 160.273 | 148.254 | 8.1 |
| 6 | 235.92 | 217.448 | 8.5 |

Figures 18, 19, 20 and 21 show the compatibility of experimental and theoretical models. A comparison was made by plotting the natural frequencies of the experimental and predicted data sets (Figure 18). The MAC and Frequency scaled MAC values between the experimental and analytical modes were calculated next in Figures 19 and 20. The correlation is very good since there is a one-to-one correspondence between the two data sets.

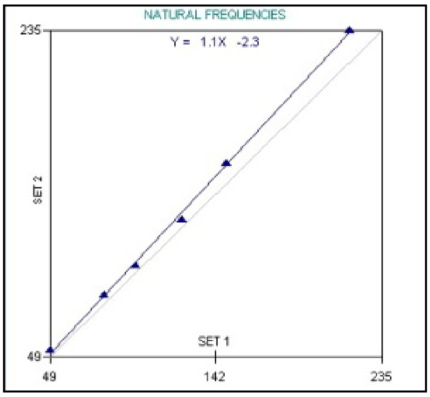


Figure 18. Natural frequency comparison.

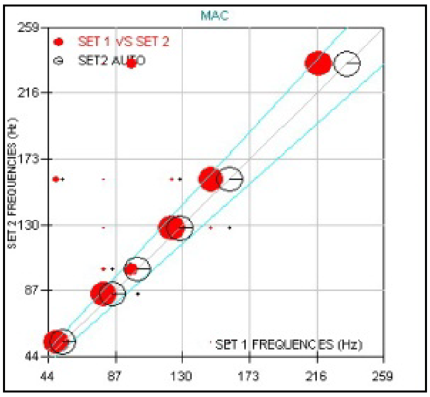


Figure 19. Frequency-scaled MAC (FMAC).

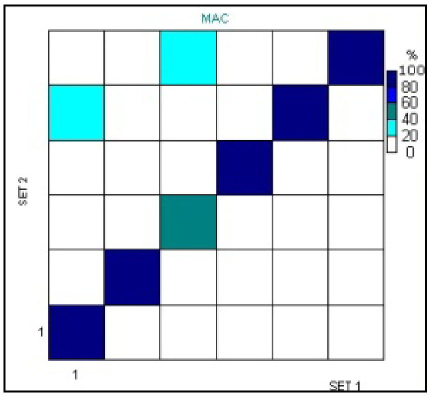


Figure 20. MAC.

The COMAC values were calculated using the 6 correlated mode shape pairs of Figure 20 and are plotted in Figure 21. Again, the results indicate very good agreement.

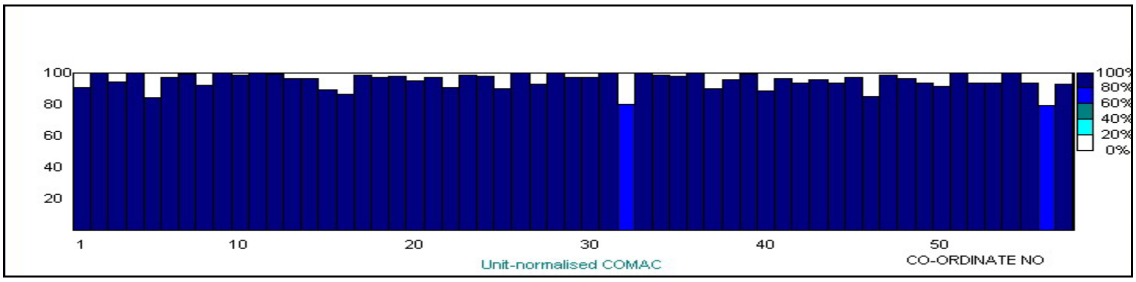


Figure 21. COMAC.

Mass and stiffness error matrices of 3D steel frame were calculated using modified error matrix method. In order to overcome the coordinates mismatch of two sets of data Reduction technique was used.

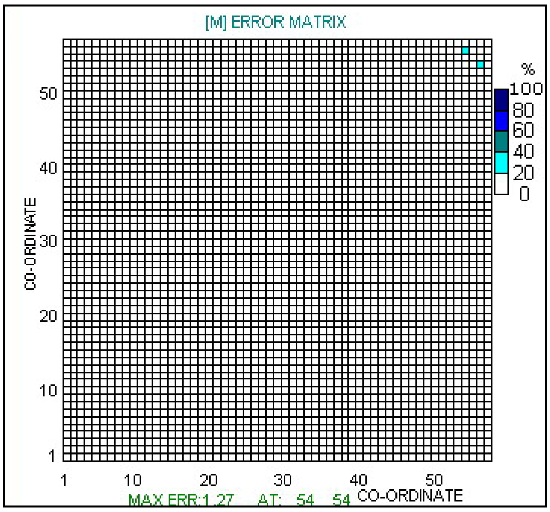


Figure 22. Mass error matrix.

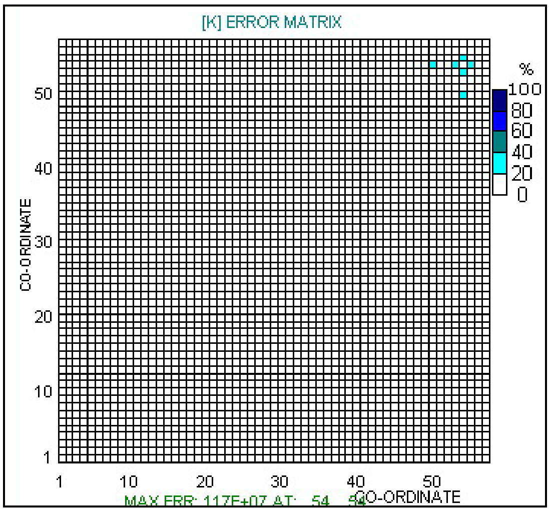


Figure 23. Stiffness error matrix.

## 4. CONCLUSIONS

Two real experimental case studies, a steel plate and a 3D steel frame, were modelled, using Modal Testing and Finite Element Method, in the first step of updating procedure. Reduction techniques were used in order to reduce the dimensions of mass and stiffness matrices for comparison purposes. A comparison was made by plotting the natural frequencies of the experimental and predicted data sets based on physical parameters. Mass and stiffness error matrices of both cases were calculated using modified error matrix method. Although the results show reasonable compatibility in both cases, the location of the errors could not be determined correctly. Besides, the mass loading effect of accelerometers is significant in the case of steel plate due to its low weight compared to 3D steel frame. It was concluded that systematic error such as mass loading effect of accelerometers can bias the measured data which may not be readily removed by updating procedures. Modal Testing demanded an experimental degree of accuracy which was not readily available from the conventional measurement techniques.

The FE Model is supposed to be inaccurate in the assumption of model updating. However, the assumption that the test results represent the true dynamic behaviour of a test structure may not be correct. Experimental data can be affected by several types of measurement errors in spite of the highly-developed instrumentation and modal parameter extraction techniques now available. It is often conveniently ignored that the measured data also contain systematic and random errors. Also the reliability of analyzed data may further be put into question by inaccuracies introduced during modal analysis, computational or superfluous modes being one of the side effects of some curve-fitting techniques employed. The reduction introduces extra inaccuracies since it is only an approximation of the full model.

## REFERENCES

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[3] N. Imamovic, “Validation of large structural dynamics models using modal test data”, *Ph.D. Thesis*, Imperial College London, 1998.