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Linear and nonlinear analysis for seismic design of piping system

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For this evaluation, two programs are studied; (1) the evaluation of ASCE methods (2) offer of the improved method for supporting structures design. In this study, four pipes and related pipe racks are designed according to scaling method and their vulnerability is assessed based on the linear and nonlinear simultaneous model of pipes and structures. Analytical results show that scaling method is matched to simultaneous model and is applicable for design of supporting structure.

Key words: Pipe support, stress analysis, pipe rack, pipe bridge.

INTRODUCTION

In Iran, according to ASCE, criteria of seismic design of piping system are based on seismic coefficient and applicable to CAESAR model of pipes. This seismic coefficient is computed by multiple coefficients; supposed as more of the ground motion and response phenomena became known. Most of these coefficients are from good engineering judgment and rely on physical concepts and equations. In most aspects designs were force-based, and required providing adequate strength to all elements of the lateral load resisting system.

Therefore, for supporting structure design, the seismic load is extracted from piping model and applied to structural model.

Therefore, though the pipes and supporting structure behave together, design of pipes and supporting structure is separated.

In this paper, ASCE method is assessed and also the scaling procedure is suggested based on this code. For this assessment, linear and nonlinear analysis of simultaneous model (contain of pipes and structure) is used as a benchmark.

MODEL DESCRIPTION

The piping systems contain three pipe rack, one pipe bridge, four flare pipes and several sleepers. The pipe racks and pipe bridge have steel bracing frames and concrete cantilever bent as the lateral resisting system, respectively. The arrangements of anchors are considered regard to pipe stress design. In this case, three type of pipe support is used. For all pipes, the weight and guide support is assumed with 12 m span and also the stopper is considered on fixed sleeper and pipe racks. Therefore, the pipe bridge only have guide and weight support.

The span of pipe bridge is selected 24 m and each bent is contained five circular column and one cap (Figure 1).

COMPUTATIONAL MODELING

The linear procedure includes the dynamic and static method. In these methods, the value of the demand is based on response modification factor; because this factor is different for each component. The ductility of steel pipe rack, concrete pipe bridge, even pipes is clear and can be consider from ASCE-7. But the ductility of combination of this component and structure is calculated by nonlinear analysis (ASCE-7, 2005).

According to ASCE-7, the structural seismic coefficient calculated by following Equation (1):

$$C_s = \frac{S_{DS} \times I}{R} \qquad (1)$$

Where:

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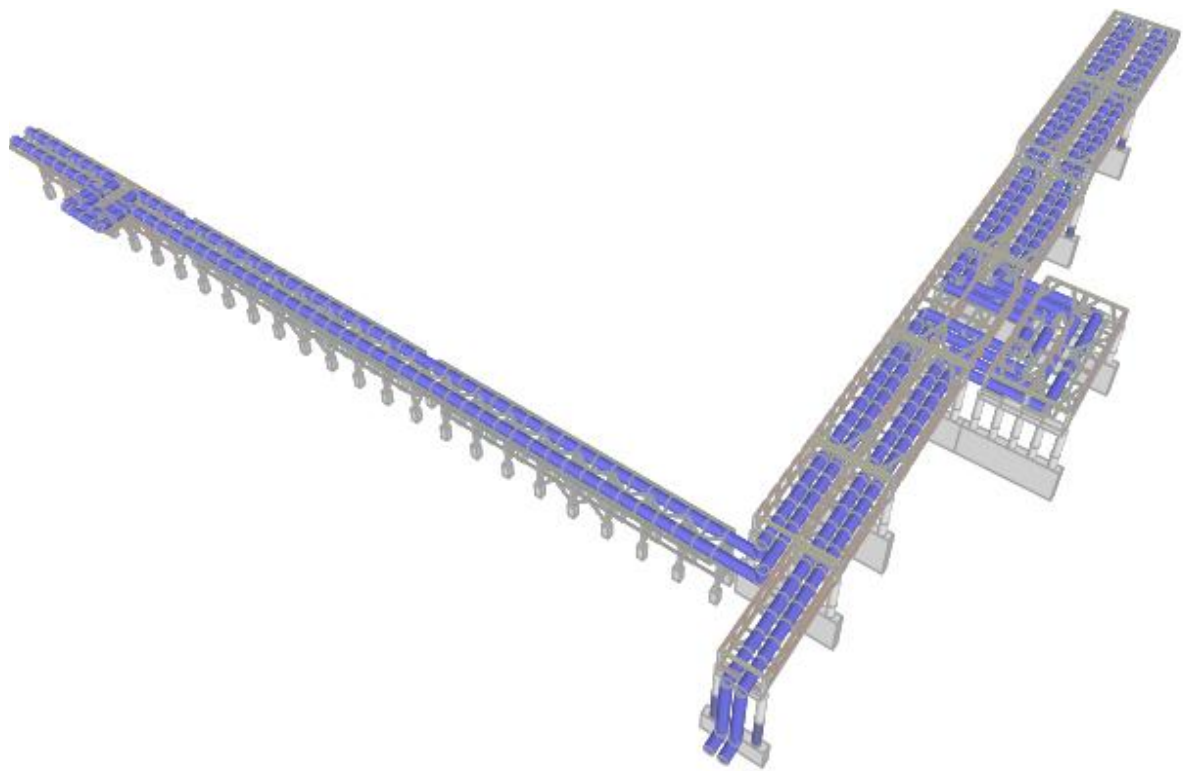

Figure 1.SAP model.

S_{DS} The design spectral response acceleration parameter in the short period range as determined from Section 11.4.4 of ASCE-7(ASCE-7, 2005)

R The response modification factor in Table 12.2-1of ASCE-7(ASCE-7, 2005)

I The occupancy importance factor determined in accordance with Section 11.5.1 of ASCE-7

Two analysis procedures are used for estimate the seismic behavior of this piping system. The linear procedure is assumed to control of design, and the nonlinear static procedure is selected to assess of total ductility. Because pipes and supporting structure are working together, therefore all structure and pipes are modeled in SAP.

Regard to Equation 1, the structural seismic coefficient is equal to 2.0 for both transversal and longitudinal earthquake. This coefficient was applied to total model in SAP. After modifying the forces based on seismic system, the result is compared.

The dynamic method includes the response spectrum and time history method. The response spectrum method uses peak modal responses calculated from the dynamic analysis for a mathematical model. Only those modes contribute significantly to the response needed to be considered. Modal responses are combined using rational methods to estimate total system response quantities. However, the response spectrum method was used for the linear dynamic procedure.

In nonlinear static method, after defining the nonlinear behavior curves, the total system is pushed to allowable lateral displacement for stopper and Guide support. This target displacement can be computed by FEMA356. After pushover analysis, the behavior of total system and members are controlled (FEMA356).

In nonlinear dynamic method, the time-histories are used. For the development of time-histories, the Bam earthquake records are used. These real time-histories were recorded on soil type I. The selected time-histories should be modified to be closer to the design ground motion conditions.

RESULTS AND DISCUSSION

Stress and deformation ratio of resisting member of supporting structure is shown in Figures 2 to 14. Figure 2 shows stress ratio for existing method and 3D-linear analysis in Morvarid-Kavian pipe bridge. Figure 3 shows stress ratio for new method and 3D-linear analysis in Morvarid-Kavian pipe bridge. Figures 4, 5, 6 show stress ratio for existing method and 3D-linear analysis in pipe rack M2, M3, M4. Figures 7, 8, 9 shows stress ratio for new method and 3D-linear analysis in pipe rack M2, M3, M4. Figure 10 shows stress ratio for new method and 3D-non linear analysis in Morvarid-Kavian pipe bridge. Figures 11, 12, 13 show stress ratio for existing method and 3D-nonlinear analysis in pipe rack M2, M3, M4. Figures 14, 15, 16 show stress ratio for new method and 3D-nonlinear analysis in pipe rack M2, M3, M4.

In this figures horizontal axis is resistance member such as brace and column. The results demonstrate that total of Pipe Bridge and pipe rack satisfies performance in the seismic condition. Even some members are overestimated, but the pipes are not locally satisfied. This

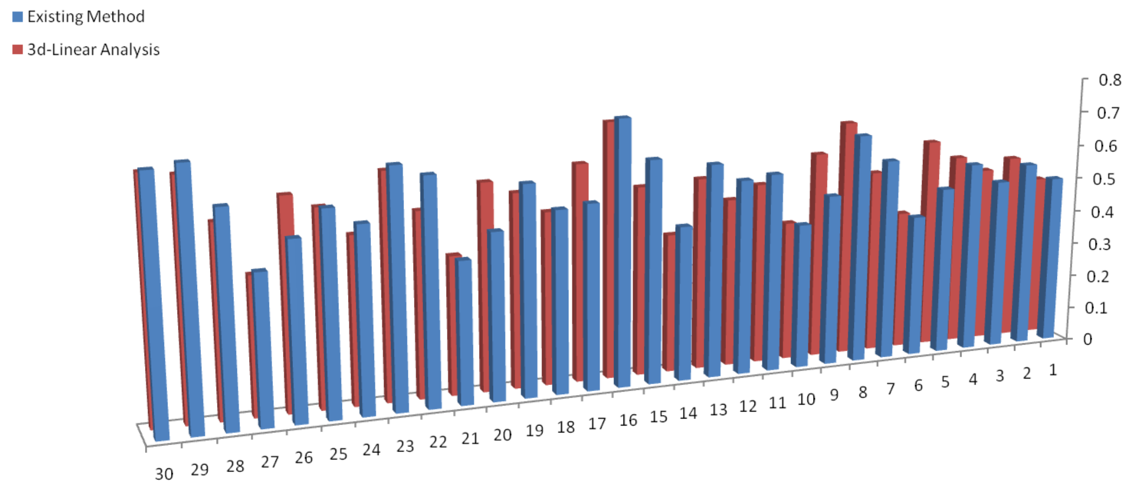

Figure 2. Stress ratio in linear method for pipe bridge (existing method and 3D-linear analysis).

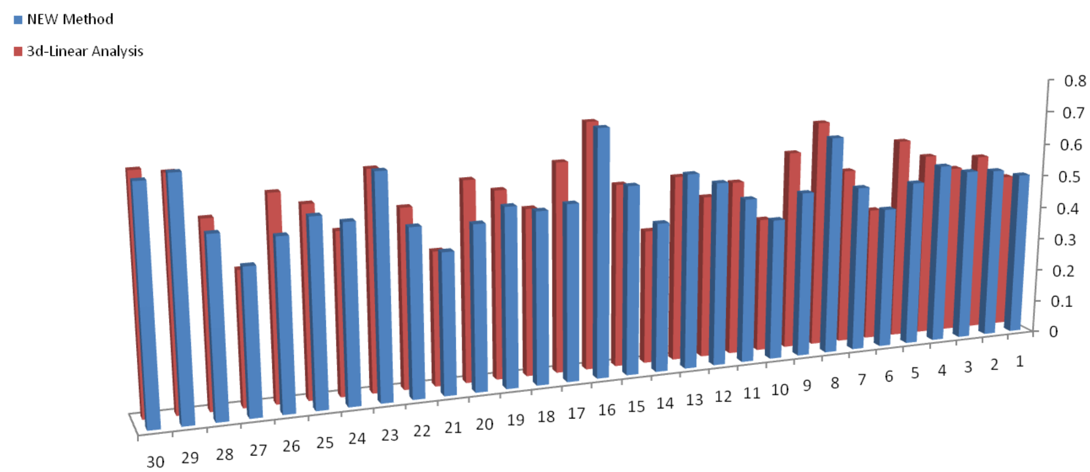

Figure 3. Stress ratio in linear method for pipe bridge (new method and 3D-linear analysis).

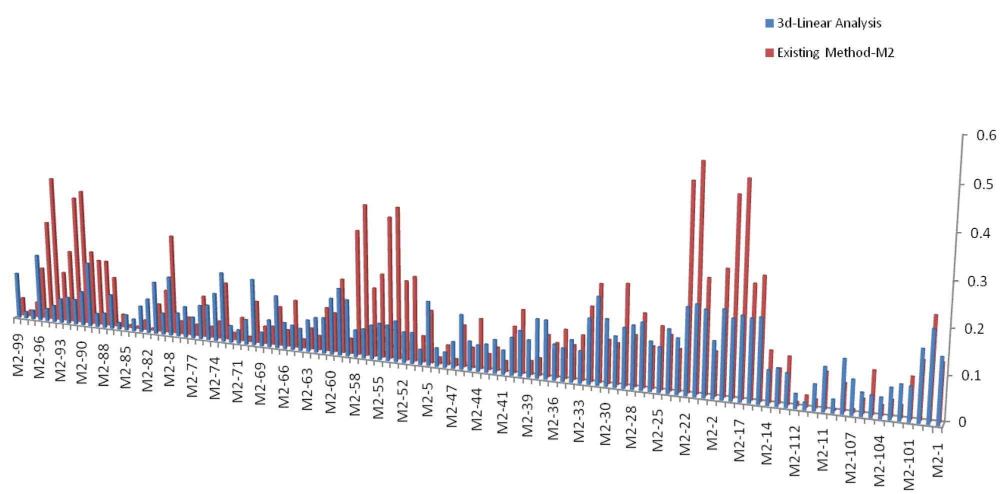

Figure 4. Stress ratio in linear method for piperack M2 (existing method and 3D-linear analysis).

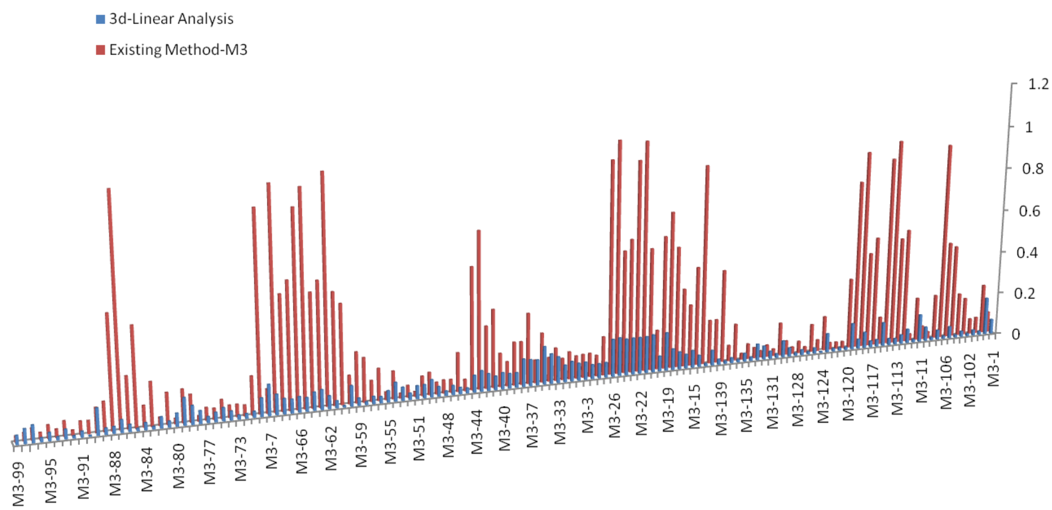

Figure 5. Stress ratio in linear method for piperack M3 (existing method and 3D-linear analysis).

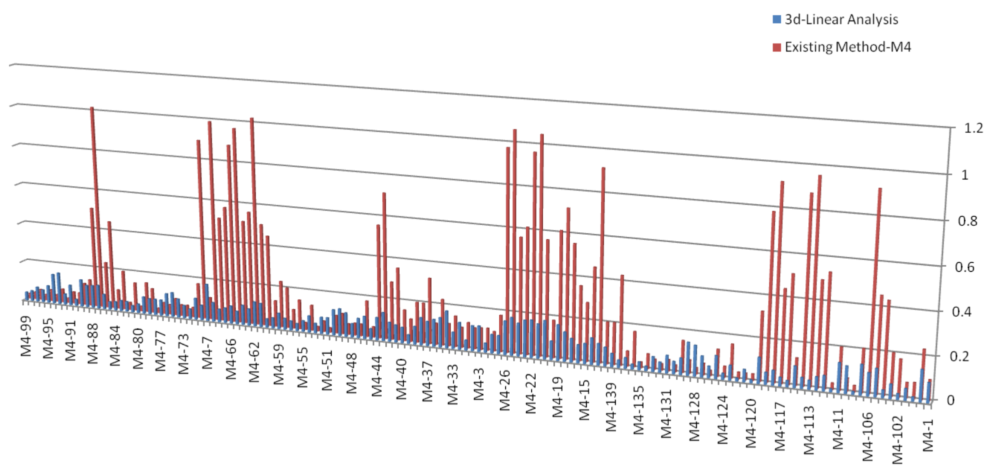

Figure 6. Stress ratio in linear method for piperack M4 (existing method and 3D-linear analysis)

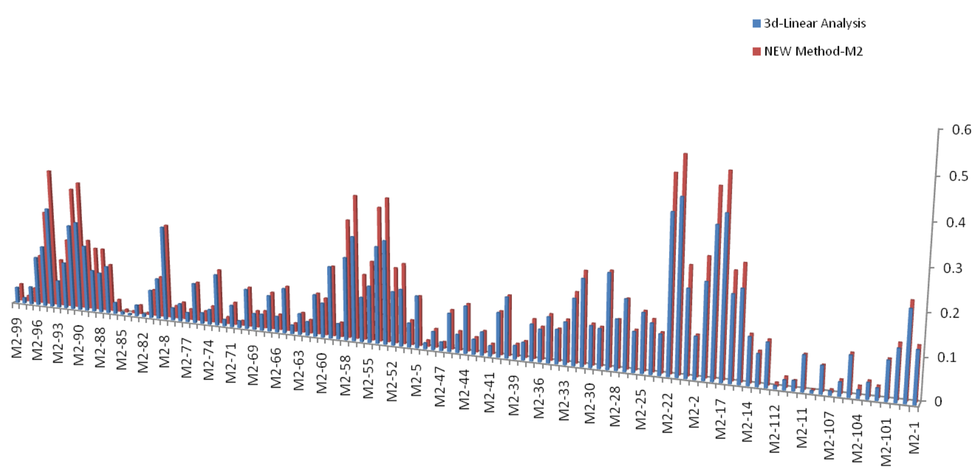

Figure 7. Stress ratio in linear method for piperack M2 (new method and 3D-linear analysis)

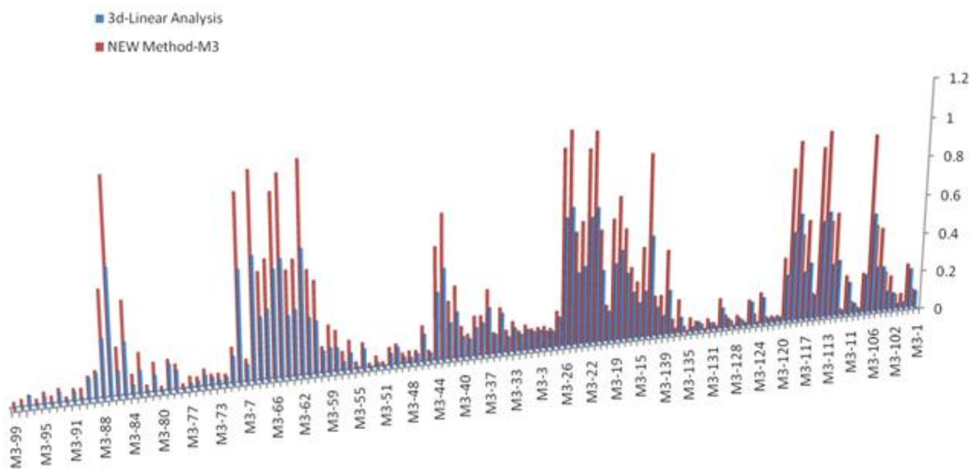

Figure 8. Stress ratio in linear method for piperack M3 (new method and 3D-linear analysis)

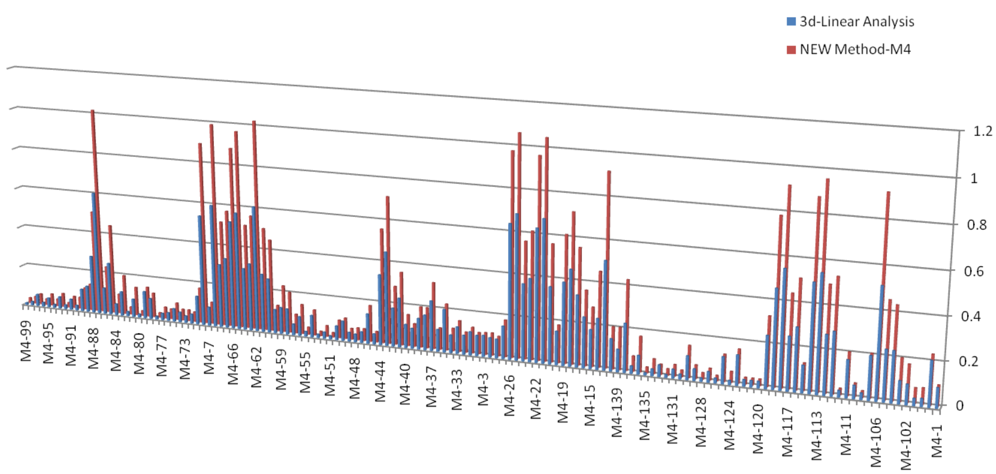

Figure 9. Stress ratio in linear method for piperack M4 (new method and 3D-linear analysis).

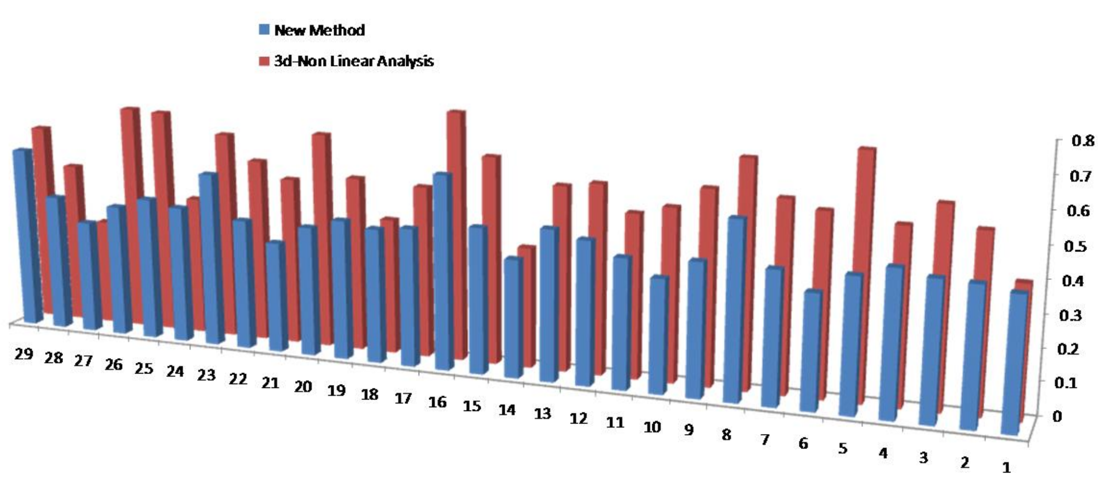

Figure 10. Stress ratio in linear method for pipe bridge (new method and 3D-nonlinear analysis)

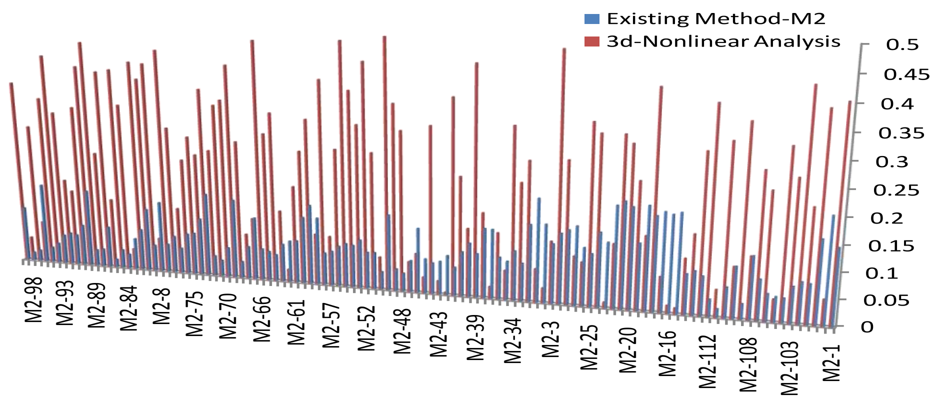

Figure 11. Stress ratio in linear method for pipe rack M2 (existing method and 3D-nonlinear analysis)

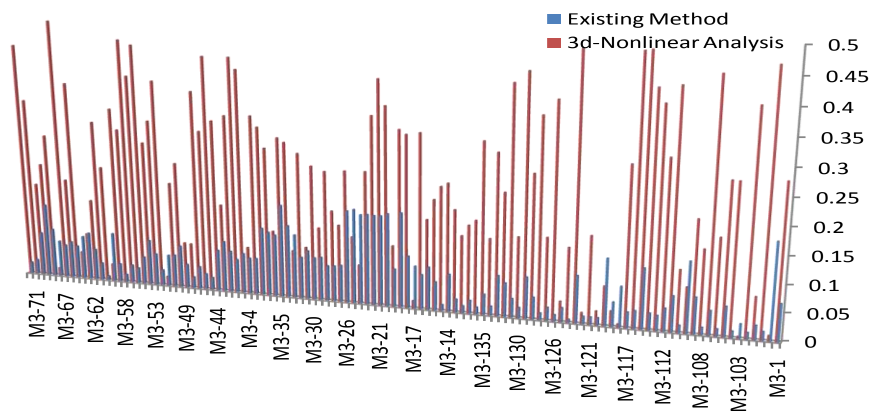

Figure 12. Stress ratio in linear method for pipe rack M3 (existing method and 3D-nonlinear analysis).

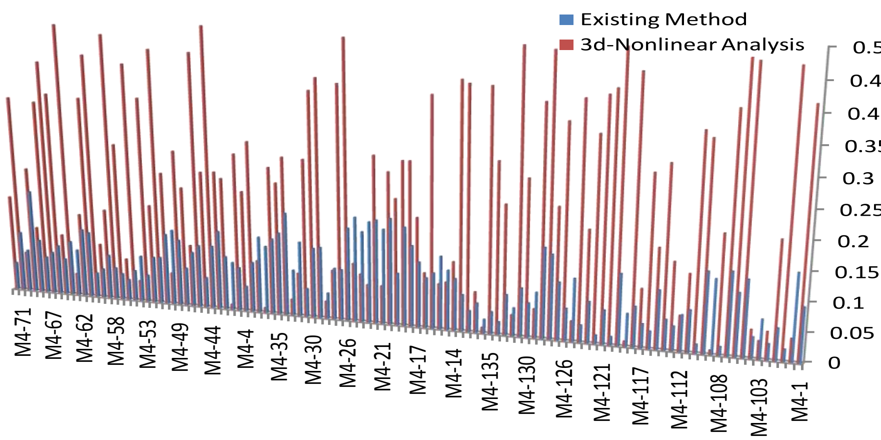

Figure 13. Stress ratio in linear method for pipe rack M4 (existing method and 3D-nonlinear analysis).

result is discussed as follows:

1. New and existing method (ASCE-7) is matched to linear static analysis of simultaneous modeling.
2. New and existing method (ASCE-7) is located upper linear dynamic analysis of simultaneous modeling.

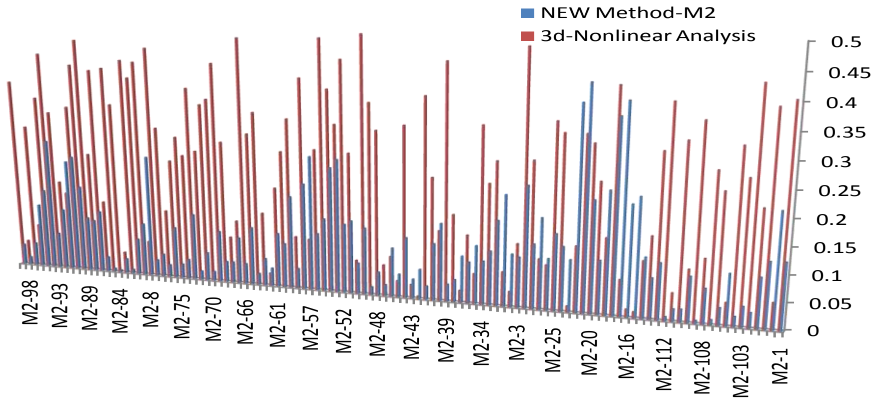

Figure 14. Stress ratio in linear method for pipe rack M2 (new method and 3D-nonlinear analysis).

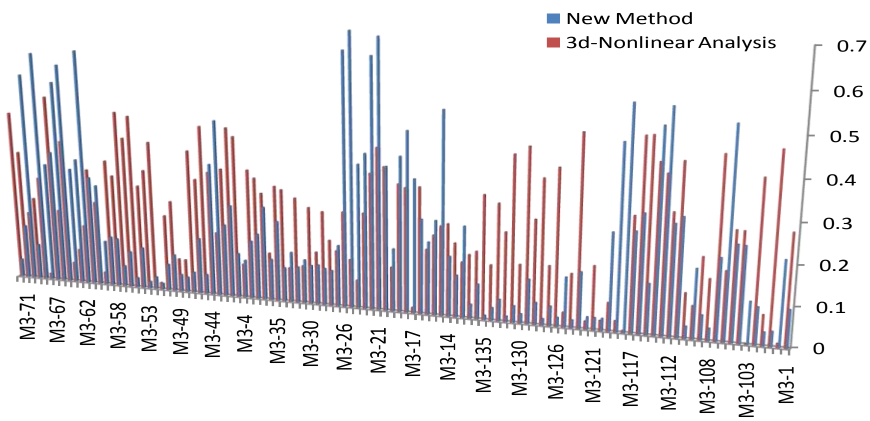

Figure 15. Stress ratio in linear method for pipe rack M3 (new method and 3D-nonlinear analysis)

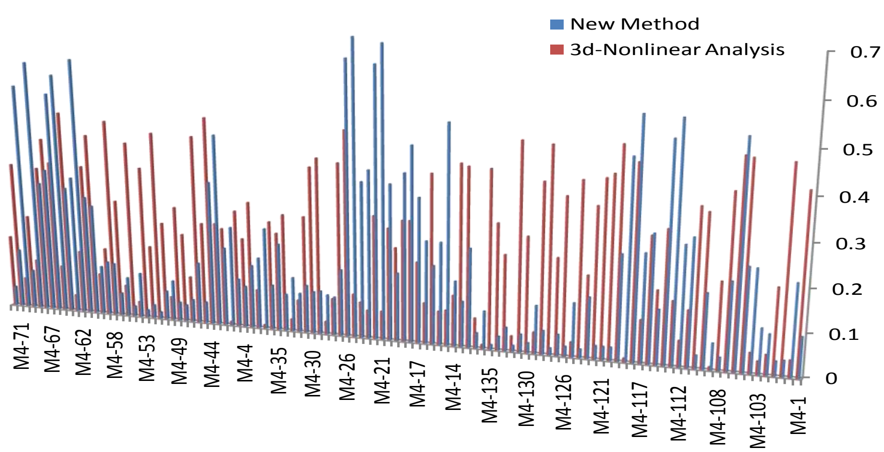

Figure 16. Stress ratio in linear method for pipe rack M4 (new method and 3D-nonlinear analysis)

3. New and existing method (and ASCE-7) is located upper nonlinear analysis of simultaneous modeling.

Therefore the result shows that new method as noted "scaling method" is applicable for design of supporting structure.

Conclusions

The petrochemical plants are contained in various pipes and are industrial structures. Therefore, the applicable design methods are required. The scaling methods have the above advantage and also are applicable for structural design. In this paper, this new method is assessed.

Results of this evaluation show that scaling method satisfies piping system performance for the supporting structures. Therefore, this method can be used for the pipe rack and pipe bridge design. According to this result, the pipes which are being design should be controlled for differential displacement. So the scaling method is reliable for piping system design while the pipe is finally controlled.

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