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Comparison Study of Effective Length Method (ELM) and Direct Analysis Method (DAM) for Piperack

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ABSTRACT

Pipe racks are structures in petrochemical, chemical and power plants that are designed to support pipes, power cables and instrument cable trays. AISC 360-05 recognize effective length method and direct analysis method for stability analysis. In this thesis a study has been conducted on the pipe rack structure to compare these methods using the 3D structural analysis program STAAD.Pro V8i considering general requirements such as influence of second order effects (P-Δ and P-δ effects), flexural, shear and axial deformations, geometric imperfections and member stiffness reduction due to residual stresses. In this thesis, a study has been conducted on piperack structure to compare Direct Analysis Method and Effective Length Method. At the end, conclusions are drawn about the comparison of these two stability methods.
Keywords : Direct analysis method, Effective length method, Notional Loads, Pipe Rack, etc.

I. INTRODUCTION

1.1 Piperacks

Pipe racks are structures used in various types of plants to support pipes and cable trays. Although pipe racks are considered non-building structures, they should still be designed with the effects of stability analysis considered. Pipe racks are typically long, narrow structures that carry pipe in the longitudinal direction. Pipe routing, maintenance access, and access corridors typically require that the transverse frames are moment-resisting frames. The moment frames resist gravity loads as well as lateral loads from either pipe loads or wind and seismic loads. The transverse frames are typically connected using longitudinal struts with one bay typically braced.

The lack of code referenced documents can lead to confusion in the design of pipe racks. The concept of stability analysis should not be ignored based the lack on code referenced documents AISC 360-10 should still be used as reference for stability analysis and design.

1.2 Stability Analysis

If stability analysis is not performed or a method of analysis is incorrectly applied, the ability of the structure to support the required load is potentially jeopardized. The analysis of nearly all complex structures is completed using advanced analysis software capable of performing various methods of analysis. Therefore omitting stability analysis in the design of structures creates unnecessary risk and is unjustified.

The AISC 360-05 code recommends using any method that ensures the stability of the structure as a whole and for individual structural elements, and meets with all the following requirements are permitted.

1. Flexural, shear and axial member deformations and all other deformations that contribute to displacements of the structure.
2. Second-order effects (both P-Δ and P- Ƨ effects)
3. Initial geometric imperfections
4. Stiffness reduction due to inelasticity
5. Uncertainty in stiffness and strength

From stability consideration of a structure, AISC chapter C suggests below two methods for determining the required flexural and axial strength of a member in the structure.

1. Effective Length Factor method (ELM) (C.2.2a)
2. Direct Analysis Method (DAM) (Appendix 7)

The application of these methods for stability analysis in design of structures varies greatly from firm to firm and from engineer to engineer.

1.3 Paper Objective

The main purpose of this thesis will be to analyze pipe rack structure, compare the results from stability analysis, and describe both positive and negative aspects of each method of stability analysis as it applies specifically to pipe rack structures. The paper will also look at some of the various issues with applying each of the methods.

Some engineers are accustomed to braced frames structures, which are not susceptible to large second order effects, therefore those designers can tend to neglect or incorrectly apply methods of stability analysis. This thesis will not only show the importance of stability analysis, but also provide suggestions on practical implementation of each method. This could potentially save time in analysis and design because the process of selecting the appropriate stability analysis method will no longer be based on trial and error but rather on educated considerations that can easily be verified after analysis.

II. METHODS AND MATERIAL

1. Pipe Rack Loading

Most company design criteria and Process Industry Practices (PIP) documents will list ASCE 7-05 as the basis for load definition and load combinations.

Basic load definitions used in STAAD pro V8i in paper are as below:

LOAD 1 Dead Load (DL)
LOAD 2 Live Load (LL)
LOAD 3 Pipe Empty Load (PE)
LOAD 4 Pipe Operating Load (PO)
LOAD 5 Pipe Hydro/ Test Load (PT)
LOAD 6 Thermal Load(TL)
LOAD 7 Pipe Friction Load (FL)
LOAD 8 Pipe Anchor Load (AL)
LOAD 9 Equipment Empty Load (EE)
LOAD 10 Equipment Operating Load (EO)
LOAD 11 Equipment Test Load (ET)
LOAD 12 Wind Load in X direction (WLX)
LOAD 13 Wind Load in -X direction (-WLX)
LOAD 14 Wind Load in Z direction (WLZ)
LOAD 15 Wind Load In -Z direction (-WLZ)

Below is listed the combined load combinations to be used in this research for design of pipe racks referenced from ASCE 7-05 Allowable strength design.

*EMPTY CONDITION WITH WIND LOAD

LOAD 101 0.6 DL + 0.6 PE + 0.6 EE + 1.0 WLX
LOAD 102 0.6 DL + 0.6 PE + 0.6 EE - 1.0 WLX
LOAD 103 0.6 DL + 0.6 PE + 0.6 EE + 1.0 WLZ
LOAD 104 0.6 DL + 0.6 PE + 0.6 EE - 1.0 WLZ
*OPERATING CONDITION
LOAD 105 1.0 DL + 1.0 PO + 1.0 TL + 1.0 AL + 1.0 EO
LOAD 106 1.0 DL + 1.0 LL + 1.0 PO + 1.0 TL + 1.0 AL + 1.0 EO
LOAD 107 1.0 DL + 1.0 PO + 1.0 TL - 1.0 AL + 1.0 EO
LOAD 108 1.0 DL + 1.0 LL + 1.0 PO + 1.0 TL - 1.0 AL + 1.0 EO
*OPERATING CONDITION WITH WIND LOAD
LOAD 109 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL + 1.0 AL + 1.0 EO +1.0 WLX
LOAD 110 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL + 1.0 AL + 1.0 EO -1.0 WLX
LOAD 111 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL + 1.0 AL + 1.0 EO +1.0 WLZ
LOAD 112 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL + 1.0 AL + 1.0 EO -1.0 WLZ
LOAD 113 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL - 1.0 AL + 1.0 EO +1.0 WLX
LOAD 114 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL - 1.0 AL + 1.0 EO -1.0 WLX
LOAD 115 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL - 1.0 AL + 1.0 EO +1.0 WLZ
LOAD 116 1.0 DL + 1.0 LL +1.0 PO + 1.0 TL - 1.0 AL + 1.0 EO -1.0 WLZ
*TEST CONDITION
LOAD 117 1.0 DL + 1.0 PT + 1.0 ET + 0.5 WLX
LOAD 118 1.0 DL + 1.0 PT + 1.0 ET - 0.5 WLX
LOAD 119 1.0 DL + 1.0 PT + 1.0 ET + 0.5 WLZ
LOAD 120 1.0 DL + 1.0 PT + 1.0 ET - 0.5 WLZ
LOAD 121 1.0 DL + 1.0 LL + 1.0 PT + 1.0 ET + 0.5 WLX
LOAD 122 1.0 DL + 1.0 LL + 1.0 PT + 1.0 ET - 0.5 WLX

LOAD 123 1.0 DL + 1.0 LL + 1.0 PT + 1.0 ET + 0.5 WLZ
LOAD 124 1.0 DL + 1.0 LL + 1.0 PT + 1.0 ET - 0.5 WLZ

2. Stability Analysis Methods

Table 1. Summary of Main Provisions for Stability Analysis and Design as per AISC 360-05

	Direct Analysis Method (DM)	Effective Length Method (ELM) (See Note 5)
AISC *Specification* Reference	Appendix 7	Section C2.2a
Limitations on the Use of the Method	None	$\Delta_{2nd}/\Delta_{1st}$ or $B_2 \le 1.5$
Analysis Type	Second-order elastic (See Note 1)	Second-order elastic (See Note 1)
Structure Geometry in the Analysis	Nominal (See Note 2)	Nominal
Notional Loads in the Analysis (See Note 3)	$0.002Y_i$ Minimum if $\Delta_{2nd}/\Delta_{1st} \le 1.5$ Additive if $\Delta_{2nd}/\Delta_{1st} > 1.5$ (See Note 2)	$0.002Y_i$ Minimum (See Note 2)
Member Stiffnesses in the Analysis	Use $EA^* = 0.8EA$ Use $EI^* = 0.8\tau_b EI$ $\tau_b = 1.0$ for $\alpha P_r/P_y \le 0.5$ $\tau_b = 4[(\alpha P_r/P_y)(1 - \alpha P_r/P_y)]$ for $\alpha P_r/P_y > 0.5$ (See Note 4)	Use nominal EA and EI
Design of Individual Members	Use Chapters E, F, G, H and I, as applicable	Use Chapters E, F, G, H and I, as applicable
	Use $K = 1$ for calculating member strengths	Determine K for calculating member strengths from sidesway buckling analysis (Can use $K = 1$ for braced frames; can use $K = 1$ when $\Delta_{2nd}/\Delta_{1st} \le 1.1$)
	No further member stability considerations	No further member stability considerations

3. Research Methodology

A general plan for the research that was conducted is presented here and is described as follows:

1. Describe in detail a typical pipe rack to be used for comparison of the methods.
2. Develop general loads and load combinations for use in the analysis models.
3. Develop a general STAAD.Pro V8i model that can be used for analysis of the Effective Length Method and Direct Analysis Method with input from [1] and [2].
4. Optimize strength only design of pipe rack structure developed in [3] using Equivalent Length Method and determine validity of method for current structure based on AISC limitations.
5. Optimize the strength only design of pipe rack structure developed in [3] using the Direct Analysis Method and compare the results to the Effective Length Method.
6. Use the models developed in [4] and [5] to compare the results.
7. By comparing the results arriving at conclusion.

III. RESULTS AND DISCUSSION

The model was analyzed with a pinned base along major axis and fixed along minor axis column. The member sizes were chosen without regard to serviceability and picked only to satisfy the load demand. Effective length method and direct analysis method were all applied to the model and the results compiled. A linear elastic analysis was completed to provide a benchmark for comparison and calculation of the ratio of second order drift to first order drift.

Table 5-1 shows the ratio of second order to first order drift ($\Delta2/\Delta1$) based on the comparison of the benchmark linear elastic analysis to the effective length method analysis. It should be noted that these maximum deflections are based on ASD load combinations. The maximum $\Delta2/\Delta1$ ratio is calculated as 1.00. Therefore, for the representative pinned base pipe rack, the effective length method is a valid method for stability analysis. Also, AISC 360-10 sets limitations for use of notional loads. Because the maximum $\Delta2/\Delta1$ is less than 1.5, notional load only need be applied to the gravity only load combinations for use in the effective length method.

Table 5-2 shows the ratio of second order to first order drift ($\Delta2/\Delta1$) based on the comparison of the benchmark linear elastic analysis to the direct analysis method analysis. As expected, the ratio $\Delta2/\Delta1$ is slightly higher based on the reduction in stiffness. The benchmark linear elastic analysis for this comparison included a reduced stiffness used in analysis. The increase in the ratio $\Delta2/\Delta1$ seen in Table 5-2 shows that the reduction in stiffness can amplify the second order effects. The maximum ratio $\Delta2/\Delta1$ is 1.10. Because the ratio $\Delta2/\Delta1$ is less than 1.7 (reduced stiffness is used to calculate drift), notional load need only be applied in the gravity only load combinations. (AISC 360-10)

Both Table 5-1 and 5-2 show the importance of consideration of stability analysis in design for above mentioned base conditions. For the representative support condition base model, stability analysis can amplify the deformation by up to 10% for this specific model. Deformation may not always be the focus of analysis and design but when checking serviceability limits; stability analysis can increase deformations significantly when compared to an elastic first order analysis.

However, based on the results of the previous two analyses, the ratio Δ2/Δ1 will be well below the 1.5 limitation set be AISC 360-10. Therefore the effective length method is a valid type of stability analysis for the representative pinned base along major axis and fixed along minor axis base pipe rack.

Demand to capacity for members should also be used when comparing the types of stability analysis methods.

The effective length method has slightly higher ratios for column design and slightly lower for beam design. For the effective length method, the column strength equations are adjusted using K to account for reduction in stiffness, but the moment can be underestimated for beams and connections which resist column rotation. The actual demand forces are listed in Table 5-4.

Based on Table 5.3 and 5.4 good correlation can be seen between the methods. The demand to capacity ratios for each method show results that are expected based on the theory used to develop each method. The member forces have slight variation between methods based on the slight differences required in analysis in the methods. All results show similar relationships between each method. It should be noted that varying geometry could have a significant effect on the ratio Δ2/Δ1 which could limit the use of effective length method. Large moments are developed in both the columns and beams and therefore the majority of the member capacity is used to resist the moment demand.

Based on the above results and observations, I recommend the direct analysis as the first choice in stability analysis for pipe racks. Effective length method provides relatively accurate results as long its requirements are met. The direct analysis provides the most accurate results and has no limitations for use. The direct analysis method can also be the simplest method to apply if modern software analysis is utilized as no front end calculations or post-analysis verification are required.

Table 5.1 Ratio Δ_2/Δ_1 effective length method

ASD Load Combination	Linear Elastic Analysis Maximum Deflection (mm)	Effective length method Maximum Deflection (mm)	Δ2/Δ1
101	0.001	0.001	1.00
102	0.001	0.001	1.00
103	23.037	22.567	0.98
104	15.408	14.937	0.97
105	1.661	0.263	0.16
106	2.05	0.263	0.13
107	1.146	0.251	0.22
108	1.536	0.251	0.16
109	0.264	0.264	1.00
110	0.262	0.263	1.00
111	24.616	22.83	0.93
112	16.461	14.674	0.89
113	0.251	0.251	1.00
114	0.25	0.251	1.00
115	24.604	22.818	0.93
116	16.474	14.687	0.89
117	0.002	0.002	1.00
118	0.001	0.001	1.00
119	12.682	11.285	0.89
120	8.865	7.467	0.84
121	0.001	0.001	1.00

122	0.001	0.001	1.00
123	13.071	11.285	0.86
124	9.254	7.468	0.81
		Maximum Δ_2/Δ_1 =	1.00

Table 5.2 Ratio Δ_2/Δ_1 direct analysis method

ASD Load Combination	**Linear Elastic Analysis Maximum Deflection (mm) reduced stiffness**	**Direct analysis method Maximum Deflection (mm)**	**Δ2/Δ1**
101	0.001	0.001	1.00
102	0.001	0	0.00
103	28.796	29.479	1.02
104	19.259	19.845	1.03
105	2.012	2.139	1.06
106	2.499	2.678	1.07
107	1.497	1.624	1.08
108	1.984	2.163	1.09
109	0.266	0.265	1.00
110	0.264	0.264	1.00
111	30.706	33.4	1.09
112	20.641	22.64	1.10
113	0.25	0.251	1.00
114	0.249	0.25	1.00
115	30.691	33.381	1.09
116	20.656	22.647	1.10
117	0.002	0.002	1.00
118	0.001	0.001	1.00
119	15.852	17.002	1.07
120	11.081	11.966	1.08
121	0.002	0.002	1.00
122	0.001	0.001	1.00
123	16.339	17.766	1.09
124	11.568	12.649	1.09
		Maximum Δ_2/Δ_1 =	1.10

	Column Maximum Forces		
	Linear Elastic Analysis	Effective Length Method	Direct Analysis Method
Strong Axis Moment (KN.m)	54	53	59

Axial Load (KN)	425	435	436.8

	Beam Maximum Forces		
	Linear Elastic Analysis	Effective Length Method	Direct Analysis Method
Strong Axis Moment (KN.m)	78	74.56	80.96
Axial Load (KN)	46	48.6	47.5

Table no. 5.4

Column Maximum Demand to Capacity Ratio		
Linear Elastic Analysis	Effective Length Method	Direct Analysis Method
0.68	0.94	0.84

Beam Maximum Demand to Capacity Ratio		
Linear Elastic Analysis	Effective Length Method	Direct Analysis Method
0.86	0.91	0.95

Table no. 5.3

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