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# Evaluation of the Stiffness Effect of Pipe Supports in Relation to Static and Dynamic Loads in a Flexibility Analysis

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***Abstract—*** *Piping flexibility analysis is done to ensure structural integrity in all operating conditions that may occur over the life of a system, whether static or dynamic. In industrial designs generally the rigidity of the support is neglected in the analysis of flexibility. The work presents an evaluation of the loads transmitted the structures in function of the rigidity of the pipe support. The evaluation was done through computer simulation using finite element techniques. The computational simulation made possible the evaluation of the forces transmitted to the support structures of an existing project of an orifice station, when considering the rigidity of the support. The work also shows that it is possible to refine projects when taken into consideration the influence of the rigidity of the supports, making a more adequate sizing the structure, portraying more faithfully the behavior of the system. The work also evaluates the influence, advantages and disadvantages in the use of stiffness in the supports with regard to the load transmitted to the support structures (support, base and tube).*

***Keywords— Stiffness, Pipe, Dynamics, Flexibility Analysis, Finite.***

## I. INTRODUCTION

Due to the disturbances that can occur during the operational life of a pumping system, the project must take into consideration besides the static loads to the dynamic loads. Dynamic loads may occur due to flow disturbances or due to the mode of excitation caused by positive displacement pumps. These loads generate in the systems abrupt changes of pressure, velocity and acceleration along the pipe, thus generating the dynamic loads. With the advancement in computational tools, it is common to simulate structural elements to determine rigidity and as a consequence to evaluate the dynamic behavior of the system under various operating conditions. The work shows that by considering the rigidity of the supports can obtain economic gains due to reduction in the volume of concrete to support the pipe.

The objective of the work is to evaluate the effect of the forces transmitted to the support structures when using the rigidity of the supports that was modeled by the finite element method. Evaluate the advantages and disadvantages of this use by means of a case study.

## II. METHODOLOGY

All real systems are complex. The mathematical model simplifies the physical system and allows it to be analyzed. The finite element method is a technique that allows to evaluate real systems through mathematical modeling. With this technique physical arrangements can be studied according to their behavior, evaluating the response of the system to undergo the action of external and internal efforts.

As one of the techniques used in this study, the linear elastic analysis for static loading adopts the following assumptions: static condition: all loads are applied slowly and gradually to achieve their total magnitudes. After reaching the total magnitude, the charges remain constant (they do not vary with time); Linearity condition: the relationship between loads and the induced responses are linear. The linearity condition is met if all model materials are in accordance with Hooke's law (Eq. 01), which states that the stress is directly proportional to strain, if the induced displacements are small enough to ignore the change stiffness caused by loading, and whether the boundary conditions do not vary during load application. The loads must be constant in magnitude, direction and distribution. They do not change while the model is being deformed.

In industrial designs standards are used with guidelines and considerations for the sizing of piping system. Discharge pipe and pipeline projects are generally used as standard ASME B31.4, this standard deals with stresses in pipes but does not address the rigidity of supports. In this way it is usual in industrial projects to consider rigid supports in the analysis of flexibility as a conservative condition of the modeling. However, the rigidity of the supports changes the response of the system, which in some cases can be detrimental to the dimensioning leading to oversizing or undersizing of the structures.

The case study was done at an orifice station which carries tailings to a dam. The orifice station functions as a charge-loss station in order to control the rejection pressures. The main transport tubing is 24 inches in diameter and a 14 inch shunt where the rupturing disc acts which is sized to break to 52kgf / cm 2. The analysis was done for three cases static (Hydrostatic testing, operation, solar radiation), dynamic and three cases (Stop by power failure, improper closure of the blocking valve and normal stop). According to the hydraulic system report, the rupture disk will rupture in the condition of improper closure of the valve.

The program used for the flexibility analysis was CAESAR II which considers infinite stiffness equal to 1012 N / cm. As a conservative practice of projects, the supports are considered as rigid in the modeling of piping systems, believing that in this condition the dimensioning would be more conservative. In special cases where they are subject to severe loads, such as long-distance pumping, this consideration can generate significant errors in both the dynamic behavior of the system and the load results.

Flexibility analyzes were performed using CAESARII software modifying only the rigidity of a specific support. This program evaluates the dynamic behavior of the system by means of solution matrices of the dynamics equation (Eq.03). The stiffness of the support was determined by the finite element method, applying a load in the three directions (x, y and z), and obtaining the displacements of the structure using Newton's second law and Hooke's law for the determination of rigidity of the support.

Hooke's law $F = k.x\ [N]$ (Eq.01)

2° Lei de Newton $\sum F = m.a\ [N]$ (Eq.02)

Dynamic equation $F(t) = M.\ddot{x} + C.\dot{x} + Kx[N]$ (Eq.03)

Where: F - applied force [N]; K-Stiffness matrix [N / m]; C - Damping Matrix [-]; M-mass matrix [kg]; a - acceleration [m / s$^2$]; x - displacement [m]; $\dot{x}$ - Speed [m / s]; $\ddot{x}$ - acceleration [m / s$^2$].

## III. RESULTS AND ANALYSIS

The support evaluated and modeled was a support type guide which restricts the 2 movements, the translation in Y and Z. In the model was considered a friction factor of 0.3 (usual for steel / steel contact). The generated physical model can be seen in Fig. 1.

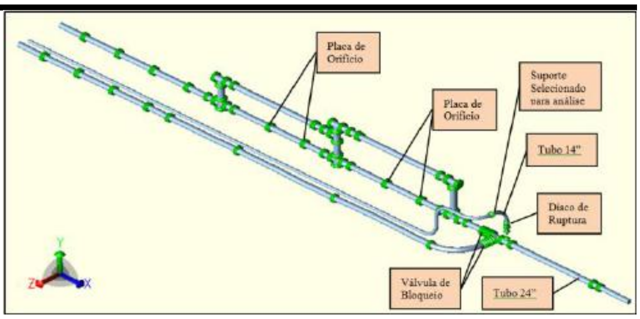


*Fig. 1: 3D model of the orifice station elaborated in CAESARII software.*

The orifice station was evaluated under the conditions shown in table 1

*Table.1: Operating conditions of the system for static and dynamic loads.*

| Carga Estática | | Carga Dinâmica | |
|---|---|---|---|
| E1 - Teste Hidrostático | T=21°C, P=30,0Kgf/cm$^2$; ρ=1000kg/m$^3$. | D1 - Parada normal do sistema | T=35°C, ΔP=32,0Kgf/cm$^2$; Tempo de manobra 120s. |
| E2 - Condição de operação | T=35°C, P=30,0Kgf/cm$^2$; ρ=1420kg/m$^3$. | D2 - Parada por queda de energia | T=35°C, ΔP=42,0Kgf/cm$^2$; Tempo de manobra 10s. |
| E3 - Insolação | T=60°C, P=NA; ρ=NA. | D3 - Parada devido a fechamento indevido da válvula de bloqueio | T=35°C, ΔP=52,0Kgf/cm$^2$; Tempo de manobra 60s. |

The carrier selected for analysis was the carrier inserted into the 14-inch rupture disk line. In the region of this support a significant pressure variation occurs when the rupture disk ruptures caused by the transient overpressure in the event of improper closing of the blocking valve (accidental case D3). The propagation of the shock wave due to improper closure of the valve causes an overpressure of the order of 52 kgf / cm2 and can be seen in the graph shown in figure 2, the transient analysis was developed using the AFT impulse software. The hydraulic transient data calculated in the AFT are presented in the time domain, these data are transformed to the frequency domain for evaluation of the flexibility by means of the Fourier transform. This transformation is done by CAESAR II itself.

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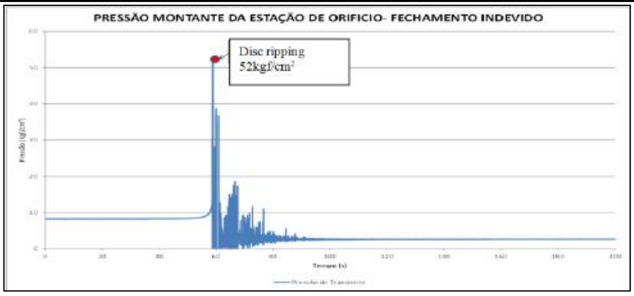


*Fig. 2: Hydraulic transient upstream of the orifice station closing valve.*

The study support was evaluated using the Ansys 16.0 software for structural analysis. The support model and the mesh test are shown in Fig 3.

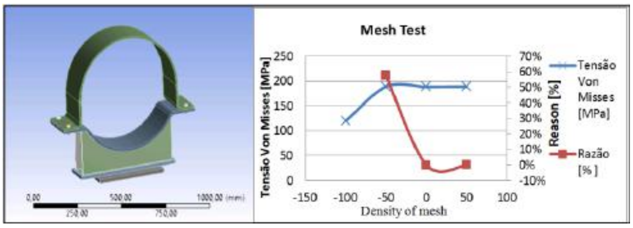


*Fig. 3: 3D model of the support in FEA the left and the right mesh test.*

The mesh test showed that the mesh used is not influencing the result for a mesh density greater than zero, obtaining a deviation of less than 0.1% in relation to the Von Misses voltage. With this model a support rigidity was obtained in the X, Y and Z directions as shown in table 2. The displacements were obtained in the center of the pipe.

*Table.2: Stiffness obtained by the finite element model.*

| Rigidez [N/cm] | | |
|---|---|---|
| **X** | **Y** | **Z** |
| 8,7E+06 | 1,4E+06 | 6,5E+06 |

With the rigidity obtained for the designed support, simulation with and without stiffness was done in order to verify the response of the system loading. The study presented reduction of static and dynamic loads with the reduction of stiffness as shown in table 3. Taking into account the rigidity of the designed support, the load showed a decrease of the transmitted load of up to 8% in the static load and of approximately 5% for the load. dynamic loading. An even more refined study can be developed for each system support in order to determine the optimal rigidity for that loading without impairing system operation.

*Table.3: Result of static and dynamic loading with and without support rigidity.*

| Modelo | Condições Operacionais | Avaliação Carregamento Estático | | | | Condições Operacionais | Avaliação Carregamento Dinâmico | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | FX [N] | FY [N] | FZ [N] | Módulo [N] | | FX [N] | FY [N] | FZ [N] | Módulo [N] |
| | | Rigid Z; Rigid GUI | | | | | Rigid Z; Rigid GUI | | | |
| Projetado | E1 | -256 | -1752 | -13713 | 13827 | D1 | 7747 | 6799 | 17153 | 20012 |
| | E2 | 39907 | 13032 | -3532 | 42129 | D2 | 244469 | 216941 | 234060 | 402011 |
| | E3 | 40144 | 14582 | 6805 | 43249 | D3 | 256589 | 34377 | 66526 | 267293 |
| | MAX | 40144 | 14582 | -15130 | 45311 | MAX | 256589 | 216941 | 234060 | 402011 |
| | | | | | | | | | | |
| Modificado com Rigidez do Suporte | E1 | -165 | -1579 | -13134 | 13230 | D1 | 7156 | 4290 | 18965 | 20719 |
| | E2 | 36451 | 11988 | -3610 | 38541 | D2 | 218036 | 223558 | 220484 | 382271 |
| | E3 | 36617 | 13406 | 6291 | 39498 | D3 | 230404 | 32965 | 80524 | 246286 |
| | MAX | 36617 | 13406 | -14495 | 41601 | MAX | 230404 | 223558 | 220484 | 382271 |
| Redução de Carga | | 8,8% | 8,1% | 4,2% | 8,2% | | 10,2% | -3,1% | 5,8% | 4,9% |

An extrapolation of the stiffness of the support was done through computer simulation to evaluate the impact of the same in static and dynamic loads. The study showed that by acting on the stiffness of the support there can be a significant gain in the reduction of static and dynamic loads. However, the dynamic load presented smaller gains in relation to the static load, this can be explained by the change in the mode of vibration of the system, because making the system more flexible also becomes more subject to greater amplitudes of vibration, changing the response of the system .

Figure 4 shows the decrease in modulus of the transmitted forces in relation to the decrease in the stiffness of the support. It is observed that the decrease in stiffness shows significant gains for the static loading, while the dynamic loading there are more moderate gains as the stiffness decreases.

In this way in industrial projects submitted to great efforts, the system must be designed for a reduction of stiffness that guarantees the operation without that the same enters resonance or has great amplitudes. A suitable working range for the case under study would be a stiffness greater than 1E + 5 N / cm, as very low stiffness can lead to excessive vibrations and damage to structures.

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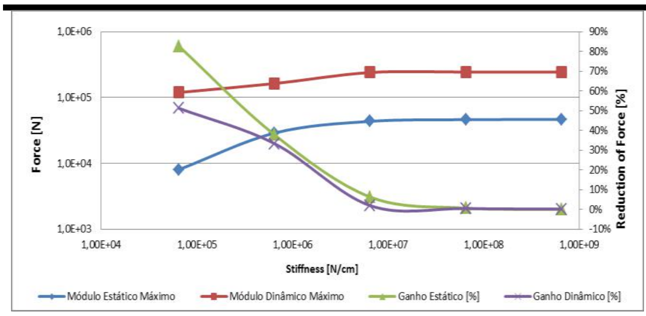


*Fig. 4: Fall of the transmitted efforts with the decrease of the rigidity of the support and its respective percentage in relation to the projected effort.*

## IV. CONCLUSION

The study showed that using the stiffness of the designed support, a reduction in modulus of the loads transmitted to structures of approximately 5% with respect to the load anticipated in the initial design corresponding to a reduction of effort of 2 tons transmitted the structures is possible;

Special attention should be given to the vibration modes of the system to avoid amplitude increase when decreasing stiffness;

The study of the stiffness of the support can contribute significantly to the reduction of the load transmitted the support structures, and in the case studied could be reduced by up to 50%, if the support was suitable for a rigidity in the order of 1.0E + 5N / cm.

As a suggestion of refinement and continuity of this study it is suggested an evaluation of the loading considering the non-linearity of the material under conditions of dynamic loading (short interval of time), and to evaluate the effects of the loads by allowing in sporadic events that the support works in the region of plasticity.

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## REFERENCES

[1] ASME B31.4 (2012). Pipeline Transportation Systems for Liquidsand Slurries. New York: American Society of Mechanical Engineers.
[2] Fish, J., Belytschko T. (2007) - A First Course In Finite Elements. England: John Wiley & Sons Ltd.
[3] Hibbeler, R. C. (2009) Vibrações. In: Dinâmica: Mecânica para engenharia. 10° Ed. São Paulo: Person Education do Brasil.
[4] Sadd, M. H. (2009), Elasticity: Theory, Applications, and Numerics, Academic Press, (2nd ed.). Burlington: Elsevier Inc.
[5] Timoshenko, S.P. e Goodier, J.N. (1970), Theory of Elasticity (3nd Ed.). New York: McGraw-Hill.
[6] Williams, J. G., Anley, R. E., Nash, D. H., & Gray, T. G. F. (2009). Analysis of externally loaded bolted joints: analytical, computational and experimental study. *International Journal of Pressure Vessels and Piping*, *86*(7), 420-427.