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# Flow Induced Vibration Analysis in Pipeline by using One-Way and Two-Way Fluid Structure Interaction

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**Abstract:** The fluid flow velocity is one of the most important parameters since it has a significant influence on the mutual interaction between the fluid domain and the structural domain. The structural deformation, structural velocity, and von Mises stress of the pipe structure, as well as the pressure and velocity of the deformed fluid were analyzed under two different types of flows: laminar and turbulent flow corresponding to the fluid velocities. This study showed that the total deformation, velocity distribution, and Von Mises stress distribution of the pipe structure increase when the inlet velocity of the fluid increases, as shown in the ANSYS Transient Structural System. Consequently, the pressure and velocity distribution in the fluid stream that absorbs the resultant or residual structural deformation also increase as the inlet velocities of the fluid increase. In both areas, the results showed that the laminar flow has much higher deformations, velocities, stresses, and pressures for the two-way FSI of the pipe structure compared to the turbulent flow. The natural frequencies and natural modes of the pipe structure were determined using ANSYS Modal Analysis. For the harmonic response, the results show that the frequency response for the turbulent flow is slightly lower for the two-way FSI of the pipe structure compared to the laminar flow in the same natural frequency range. Based on the research conducted, it is evident that one-way FSI and two-way FSI provide similar results in terms of the deformation of the structure and the resulting structural deformation.

**Keywords:** Fluid Structure Interaction, Flow Induced Vibration, Pipe Structure, Vibrations

## 1. Introduction

The interaction between fluids and solids is a widespread phenomenon that can be observed in nature, such as the deformation and vibration of trees. Fluid-structure interaction (FSI) can be described as the mutual interaction between a solid structure and a flowing fluid that occurs when the solid and fluid move [1-3]. These two motions are interdependent and usually occur when the structure is subjected to external or internal fluid flow. The deformed structure in turn causes a change in the flow pattern. Therefore, the interest in this study is on the simulation analysis of one way and two-way FSI and the effect of flow velocities on the dynamic properties and response of pipe structure. In this study, the simulation for one-way and two-way FSI involves the use of ANSYS Workbench software, which combines the ANSYS Fluent fluid solver with the ANSYS Transient Structural solver.

The fluid flow will change if there are changes in the body caused by changes in the pipe and interrupt the fluid flow, causing vibrations in the structure of the pipe. In this case, there was some concern that the flow would become unstable due to the defects, which would eventually affect the structure [4-6]. In addition, it was difficult to determine the defect because it was located inside the pipe [7]. Apart from that, the knowledge and information about the structure of the pipeline is very limited due to internal defects.

The main objective of this research is to investigate the effect of internal defects in pipeline towards the velocity profile and pressure drop of fluid flow using one-way and two-way FSI. Other than that, to compare and analyze the vibration response of the pipe structure based on one way and two-way FSI.

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## 2. Methodology and Simulation Setup

The pipes are modelled using ANSYS DesignModeler, which is available in ANSYS Workbench 2021 R2 software. The standard materials for steel and gasoil-liquid in ANSYS are used as material properties for the pipe and the liquid section [8]. The details of the geometry and simulation analysis are explained in the following sections. Figure 1 shows the overall 3D modelling of the simulation model with the fluid field and the fixed free end beam using DesignModeler. The inlet of the pipe is a fully developed flow with uniform longitudinal velocities of 0.0131 m/s and 0.0787 m/s that is introduced at the inlet correspond to the Reynolds number of 2,000 and 12,000 for laminar flow and turbulent flow respectively. The entire boundary (side and bottom walls) was a free-flowing wall, in which the velocity near the wall is not delayed by effects of the friction.

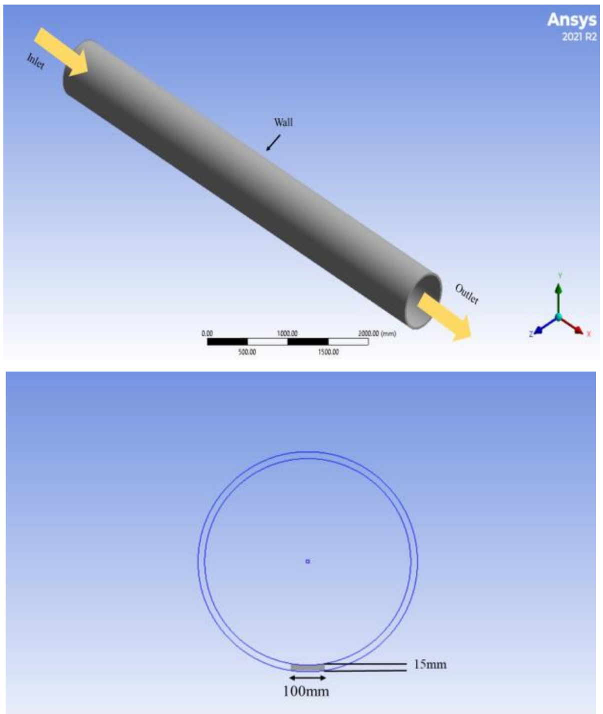



**Fig. 1 - The computational geometry of 3D modelling (pipe)**

### 2.1 ANSYS Simulation

In this simulation method, Static Structural Analysis, Fluent Analysis are used for the simulation of one-way FSI while Transient Structural Analysis, Fluent Analysis and System Coupling analysis are connected along for the simulation of two-way FSI of pipe. Moreover, Modal Analysis shared a similar structural geometry with Transient Structural system to work out the natural frequencies and its mode shapes [9-11]. Harmonic response is connected to the Modal to analyze the amplitude response below the excitation of specific vary of frequencies. Figure 2 and 3 shows the 5 main analysis system are connected in Project Schematic.

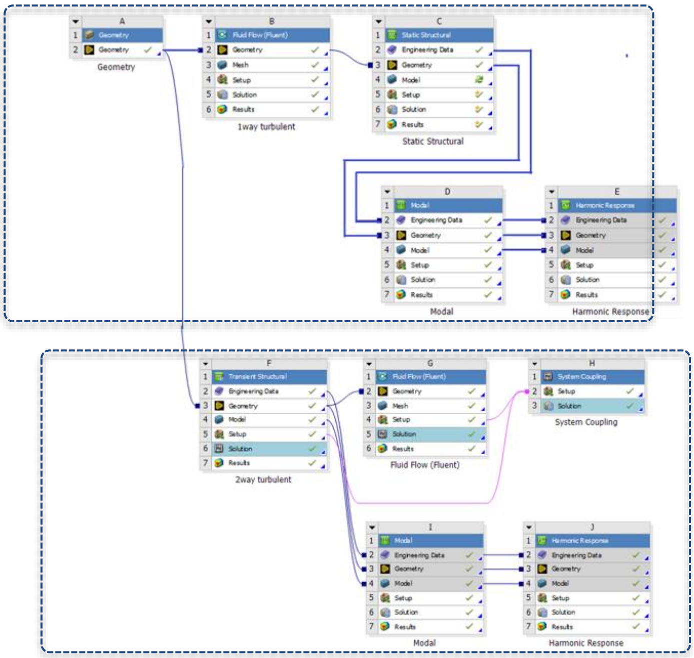


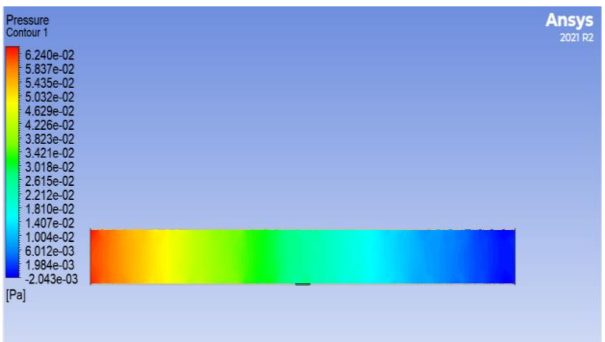
**Fig. 2 – ANSYS Workbench overall diagram system; one-way FSI (upper box), two-way FSI (below box)**

## 3. Results and Discussion

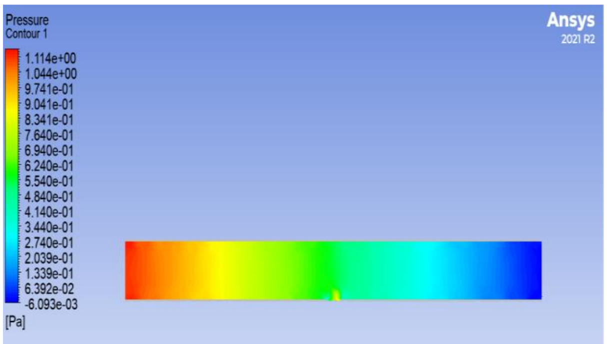
The results will discuss on the flow analysis in the pipe, structural and modal analysis in term of contour analysis while there are harmonis response of pipe when the fluid flow in the pipe. Furthermore, the analysis to be assisted by the means of velocity streamline, velocity contour and pressure contour.

### 3.1 Flow analysis in pipe

Fluid Flow (FLUENT) analysis is used to simulate the fluid analysis in pipe to get pressure distribution under laminar and turbulence circumstances for one-way and two-way FSI. Figure 3 demonstrates the pressure contour of a pipe under laminar and turbulent flow for one-way FSI, while Figure 4 demonstrates the pressure contour of a pipe under laminar and turbulent flow for two-way FSI. The maximum pressure of the fluid flow for each contour are tabulated in Table 1. The overall pressure from structural deformation under turbulent flow is slightly higher than the laminar flow for FSI.

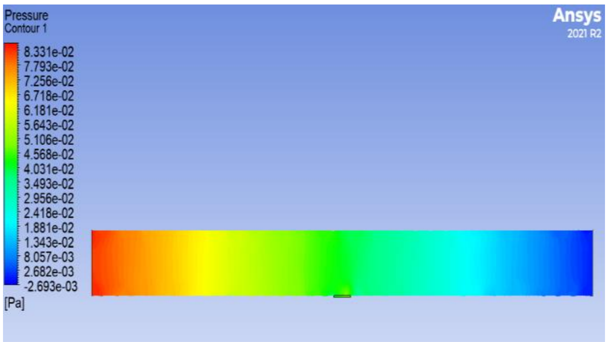



(a)




(b)

**Fig. 3 – Pressure contour one-way (a) laminar flow (b) turbulent flow**

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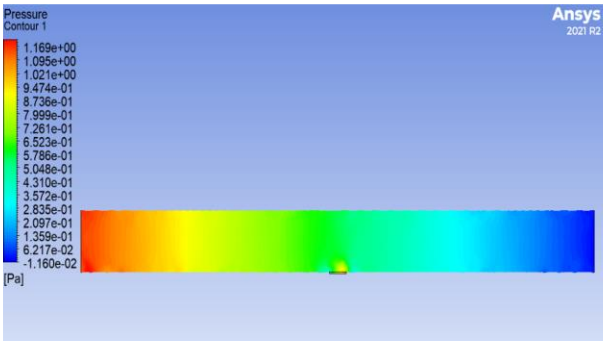



(b)

**Fig. 4 – Pressure contour two-way (a) laminar flow (b) turbulent flow**

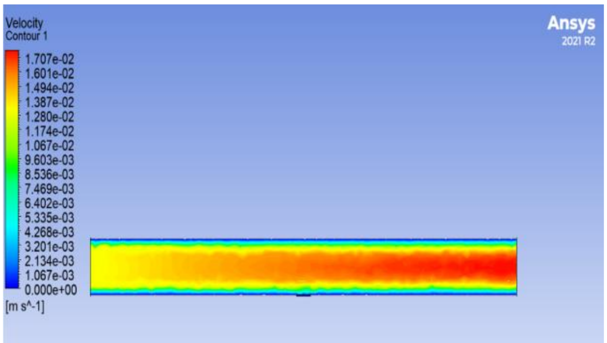
**Table 1 – Summary of fluid pressure.**

| FSI | Laminar | Turbulent |
|---|---|---|
| One-way | 0.0634 Pa | 1.114 Pa |
| Two-way | 0.0833 Pa | 1.169 Pa |

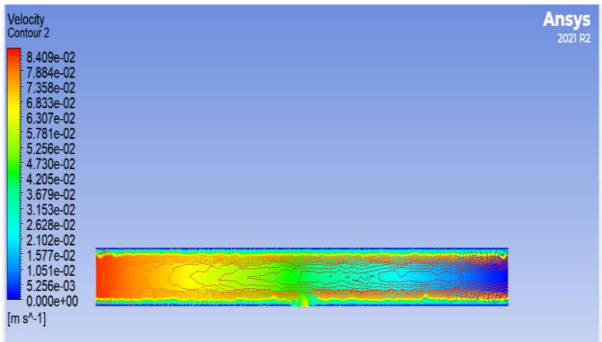
As shown in figure 5 and 6, also in Table 2, the overall resultant fluid velocity from structural deformation for two-way FSI is lower than one-way FSI. The gasoil-liquid flowed through the 6 m long pipe. There are two types of flow, laminar and turbulent flow with *Re* = 2,000 and *Re* = 12,000, respectively. The figures below show the velocity profile for laminar and turbulent flow for one-way and two-way FSI. The interaction between the surface area in the pipe and the fluid velocity is related.

**Table 2 – Summary of maximum velocity.**

| FSI | Laminar | Turbulent |
|---|---|---|
| One-way | 0.0176 m/s | 0.0841 m/s |
| Two-way | 0.0131 m/s | 0.0034 m/s |

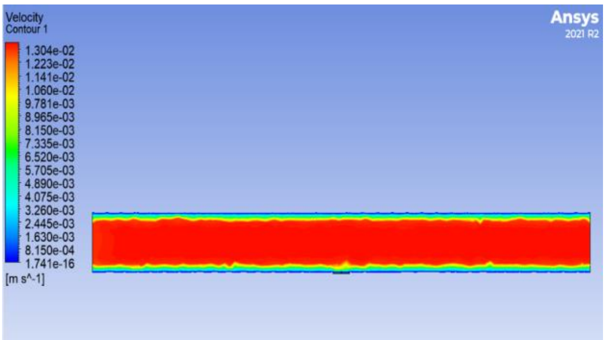



(a)

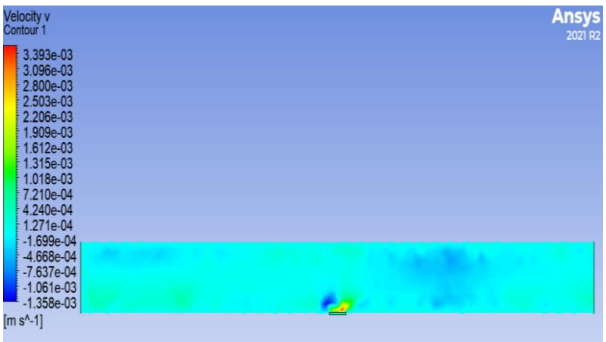



(b)

**Fig. 5 – Velocity contour two-way (a) laminar flow (b) turbulent flow**




(a)




(b)

**Fig. 6 – Velocity contour two-way (a) laminar flow (b) turbulent flow**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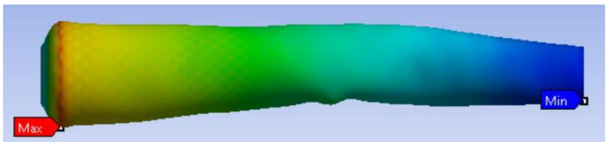
### 3.2 Structural analysis

Static structural analysis was used to analyze Von Mises stress and deformation induced in the pipeline structure. The structure of the pipeline changes when a force is applied to it. The forces applied to the pipe were located at both ends of the pipe, at the inlet and outlet of the pipe. In the analysis setting, the load was transferred from the fluid to the solid. The velocity has changed due to the defect in the pipe and affects the pressure difference across the pipe structure. Figures 7 and 8 show the Von Mises stress of the pipe structure at different Reynolds numbers and defect types. The location of the maximum and minimum are marked to show the effect of the Von Mises stress on the pipe structure.

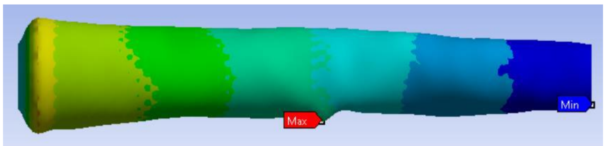

(a)


(b)

**Fig. 7 – Von-Mises stress profile of erosion defect of one-way FSI one-way (a) laminar flow (b) turbulent flow**




(a)




(b)

**Fig. 8 – Von-Mises stress profile of erosion defect of two-way FSI one-way (a) laminar flow (b) turbulent flow**

**Table 3 – Summary of Von-Mises stress.**

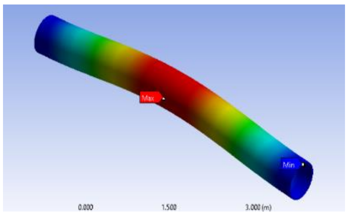
| FSI | Laminar | Turbulent |
|---|---|---|
| One-way | 3.2613 MPa | 40.36 MPa |
| Two-way | 1.2888 MPa | 20.45 MPa |

### 3.3 Modal analysis of fixed-free end beam

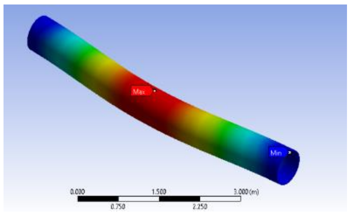
In this case, six natural frequencies are determined for the pipe structure for both FSI. The natural frequencies remain unchanged regardless of the different flow regimes. Table 4 shows the natural frequencies of the structure using ANSYS. Figure 9 shows the summary of the results of the natural modes in the ANSYS and SolidWorks simulations.

**Table 4 – Summary of Von-Mises stress.**

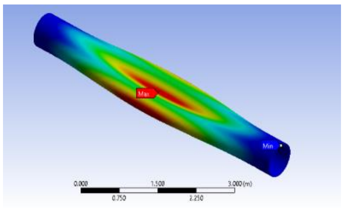
| Mode, *n* | One-way (Hz) | Two-way (Hz) |
|---|---|---|
| 1 | 107.45 | 107.48 |
| 2 | 107.63 | 107.63 |
| 3 | 153.99 | 163.96 |
| 4 | 154.57 | 164.37 |
| 5 | 183.65 | 190.50 |
| 6 | 183.70 | 190.68 |



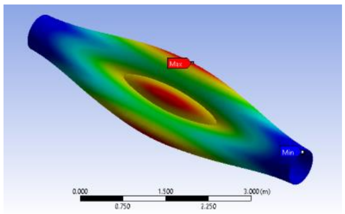
First mode shape



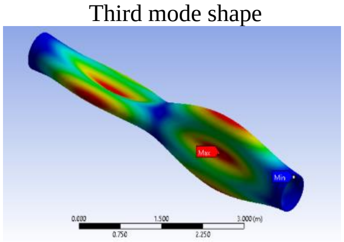
Second mode shape



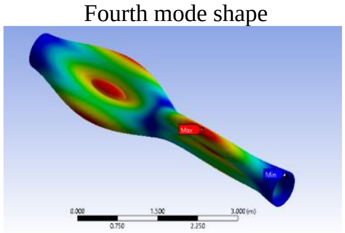
Third mode shape



Fourth mode shape



Fifth mode shape



Sixth mode shape

**Fig. 9 – Summary of mode shapes using ANSYS Modal analysis**

### 3.4 Harmonic response of pipe

Harmonic Response Analysis is conducted to study the response of a system to excitation at specific range of frequencies. The range of harmonic frequency analysis is from 0 Hz to 300 Hz for all the fluid flow cases. The result of harmonic response for laminar flow of two-way FSI has been shown in Figure 10. The summary of peak response for two different flow in both FSI is show in Table 6. There occurs the max. amplitude and the amplitude in laminar flow is much higher compared to turbulent for both FSI.

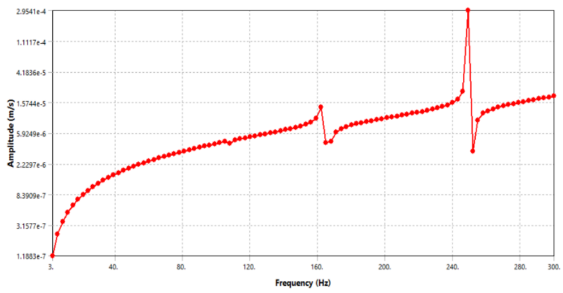



**Fig. 10 – Frequency response of laminar flow of two-way FSI.**


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**Table 6 – Summary of peak response for two different flows in both FSI**

| FSI | Laminar | Turbulent |
|---|---|---|
| One-way | 0.5493 m/s | 0.5350 m/s |
| Two-way | 0.2954 m/s | 0.2837 m/s |

## 4. Conclusion

The objectives of this study is to investigate the effect of internal defects in pipeline towards the velocity profile and pressure drop of fluid flow using one-way and two-way fluid structure interaction approaches. The ANSYS Workbench is used to implement the FSI multiple analysis system, such as, transient structural analysis, fluent analysis, and system coupling. The two-way coupling method was applied to study the mutual interaction between the pipe structure and the fluid domain. In these studies, the same geometry model is used with two different Reynolds numbers, divided into laminar flow and turbulent flow. In summary, in this study, the goal of this study was achieved, which was to determine the velocity profile and pressure drop of the fluid flow in the pipe caused by a defect. The one-way and two-way FSI of the pipe structure and also the different inlet flow velocities were represented by using ANSYS simulation software.

Moreover, these simulations are also supported by previous studies and research works. In summary, the objectives of this study have been achieved. The recommendation can be made is to implement different types of fluid for analyzing different behavior of FSI of pipe. Other than constant inlet velocity, the user-defined equations or sinusoidal inlet fluid velocities can be used to study various FSI behavior.

## Acknowledgement

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## References

[1] Bano, T., Hegner, F., Heinrich, M., and Schwarze, R., "Investigation of fluid-structure interaction induced bending for elastic flaps in a cross flow." *Applied Sciences*, 10(18) (2020): 6177 https://doi.org/10.3390/APP10186177

[2] Moussou, P., Lafon, P., Potapov, S., Paulhiac, L. And Tijsseling, A., "Industrial cases of FSI due to internal flows. In: Proc. of the 9th Int. Conf. on Pressure Surges, volume 1, (2004): 13–31.

[3] Nazihah, M.N., "Analysis of vortex shedding in various body shapes." University Tun Hussein Onn Malaysia, 2015.

[4] Pu, J., Xu, J., Li, G. et al. "Experimental study on damping characteristics of pipe vibration in liquefied silt." In: The Twenty-third International Offshore and Polar Engineering Conference, International Society of Offshore and Polar Engineers, 2013.

[5] Tijsseling, A., "Fluid-structure interaction in liquid-filled pipe systems: a review." *Journal of Fluids and Structures*, 10(2) (2002): 109–146.

[6] Veerapandi, R., Karthikeyan, G., Jinu, G. And Kannaiah, R., "Experimental study and analysis of flow induced vibration in a pipeline." In: International Journal of Engineering Research and Technology, volume 3, ESRSA Publications, 2014.

[7] Wang, G., Liang, B., Li, H. et al. "Vortex-induced vibrations of submarine freespan pipelines using turbulent flow model simulation." In: The Fifteenth International Offshore and Polar Engineering Conference, International Society of Offshore and Polar Engineers, 2005.

[8] Parameshwaran, R., Jathin, S., and Rao, D., "Fluid-structure interactions and flow induced vibrations: A review." *Procedia Engineering*, 144 (2016): 1286–1293.

[9] Ahamed, M., Atique, S., Munshi, M., and Koiranen, T. "A concise description of one way and two way coupling methods for fluid-structure interaction problems." *American Journal of Engineering Research*, 6 (2017): 86–89. http://www.ajer.org/papers/v6(03)/O06038689.pd

[10] Wu, K., Yang, D., and Wright, N., "A coupled SPH-DEM model for fluid-structure interaction problems with free-surface flow and structural failure." *Computers and Structures*, 177 (2016): 141–161.

[11] Sambu, M., Badrin, M. I., Zaman, I., Manshoor, B., Khalid, A., Chan, S. W., and Mohamed Salleh, M. "Flow-Induced Vibration of Cantilever Beam by One-Way Fluid Structure Interaction Approach." *Journal of Complex Flow*, (2022) 4(2), 39-43.