Design of a Biaxial Pipe Testing Frame

ASCE Technical Paper

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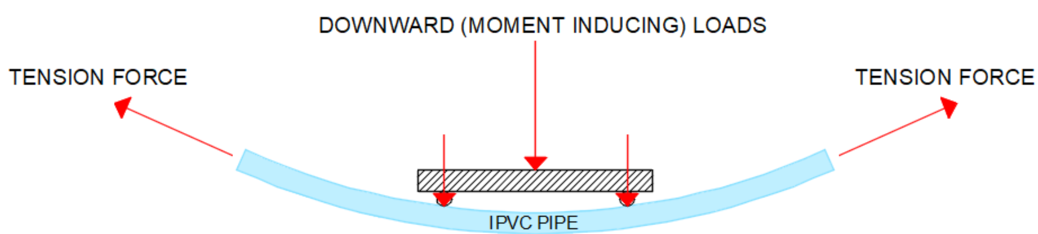
1. Introduction

This report describes the design of a biaxial bending frame. This frame is used to test iPVC pipes in the University of Colorado Boulder's Center for Infrastructure, Energy, and Space Testing (CIEST). The biaxial bending test is useful for determining the strength and stiffness of pipes sent to the lab for testing. In the future the frame will be used as part of a project by The Advanced Research Projects Agency - Energy (ARPA-E) to assess natural gas pipe rehabilitation technologies. The biaxial test is particularly useful in determining how pipes and pipe rehabilitation technologies respond to lateral deformation and deflection due to overhead loads, frost heave, and excavation as these loads can cause both bending and tension forces (Dixon).

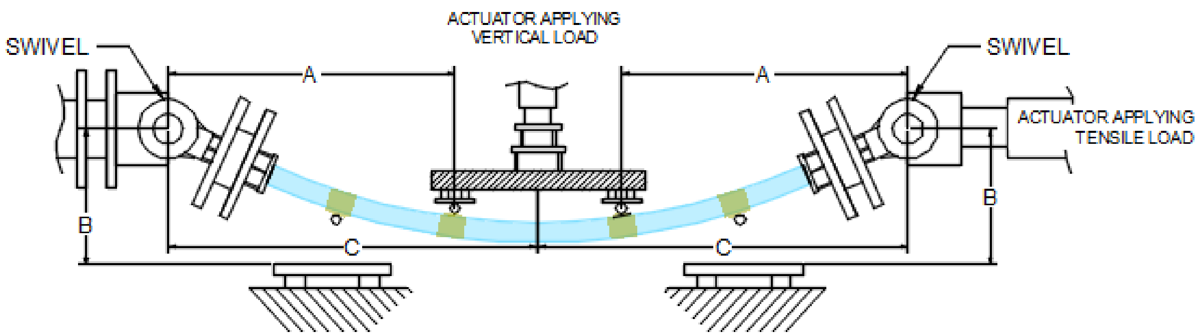
2. Biaxial Bending Frame Design Considerations

The biaxial bending frame design requires additional considerations beyond those of a traditional axial testing frame or four-point bending frame. In a biaxial bending test, the pipe is subjected to both bending and axial tension loads.

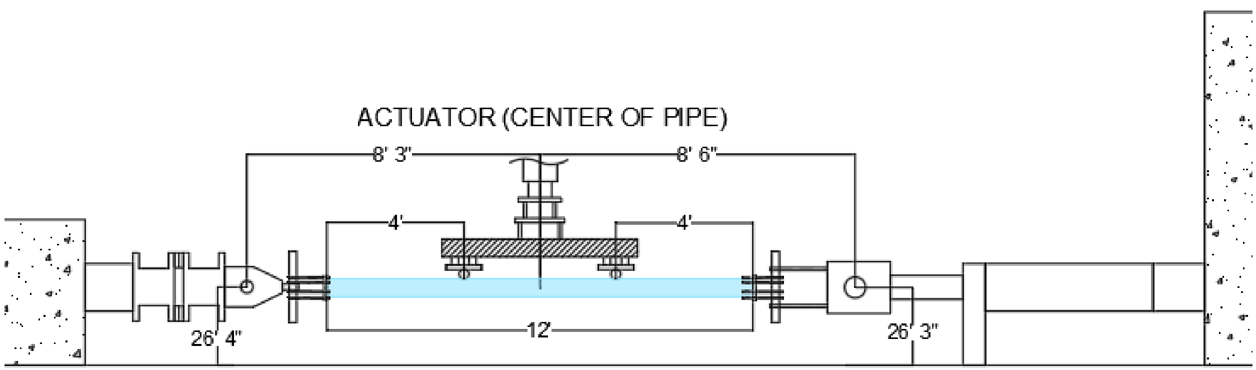


In order to generate tension loads normal to the end caps of the pipes while simultaneously allowing for a free range of motion in bending, swivels are attached to either end of the pipe. The weight of these swivels induce a load on the pipe. To simplify calculations and allow both the axial and bending elements of the biaxial test to perform properly the frame was designed with the following criteria in mind:

1) The centers of rotation of the swivels must be equidistant from the center of the pipe.
2) The centers of rotation of the swivels must be the same height above the ground.
3) The pipe must begin the test completely level.



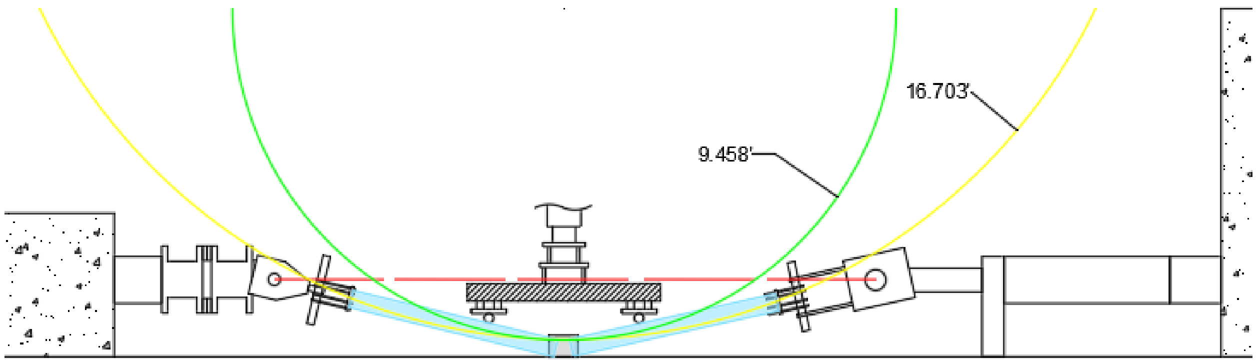
Another important consideration when designing the biaxial frame was the available materials. Plates and spacers were only available in certain sizes, while there were no two identical swivels in the lab. We selected swivels based not only on criteria (1) and (2) but also based on weight. Lighter swivels induce lower loads in the pipe, which reduces deviations from ideal biaxial bending test results. The final design is shown with dimensions below.



The left swivel (8'3" from actuator) does not move horizontally, it stays fixed aside from rotation. Therefore, the center of the swivel maintains an 8'3" distance from the actuator throughout the duration of the test. The center of the swivel attached to the actuator on the right has variable distance from the actuator as the actuator retracts during the test to induce a tension force in the pipe. Despite the slightly different lengths from the actuator to each swivel, the pipe is centered perfectly around the center of the actuator using the bolts which connect the pipe end caps to the plates holding each end.

4. Biaxial Bending Frame Deflection and Curvature

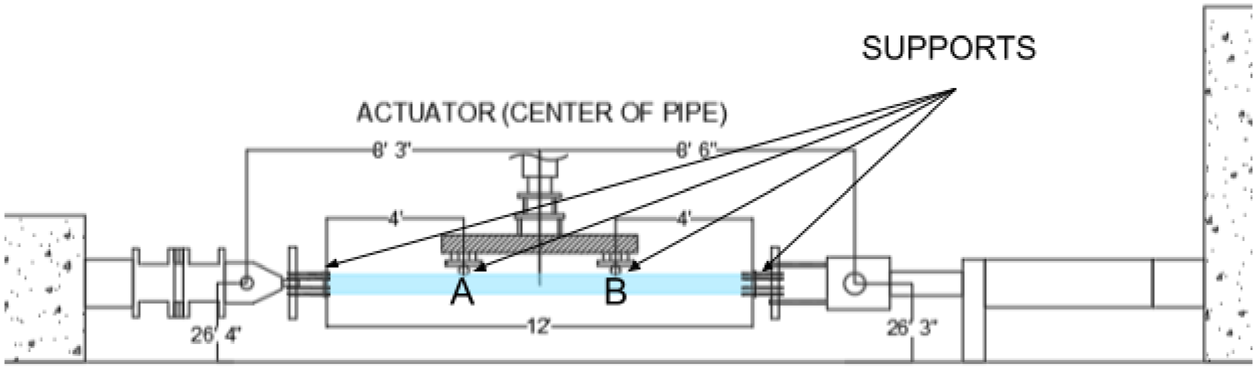
When designing any bending frame, it is important to maximize the potential for pipe deflection and curvature while working within the other design constraints. The relationship between curvature and radius of curvature (ROC) is given by curvature = $\frac{1}{\rho}$, where ρ is the radius of curvature. In analyzing the ROC of a pipe in four-point or biaxial bending, there are two available measurements. The first is the measurement of ROC over the whole length of the pipe while the second is the local ROC within only the inner third of the pipe. The curvature within only the inner third is the measurement of interest as it more directly relates to the maximum stresses and deflections of the sample pipe. The maximum radius of curvature of a 12' sample pipe in the biaxial bending frame was calculated geometrically in AutoCAD.



From the diagram, we see that the ROC of the entire pipe length is approximately 16'8" while the ROC of the inner third of the pipe length is 9'5$\frac{1}{2}$". This ROC is significantly higher than the 4-point bending frame also found in the CIEST lab, however a pipe under biaxial loading should have less vertical deflection (and a subsequently higher ROC) than a pipe under purely bending loads. A pipe sample in the biaxial bending frame is expected to fail due to a combination of tensile and bending forces, so it will reach a lower curvature before failure than a traditional bending test.

5. Biaxial Bending Frame Induced Loads

Assuming the weight of each swivel is supported entirely by the pipe, we can calculate the additional forces in the pipe due to the frame. The biaxial frame supports the pipe with the end swivels and the rollers which are connected to the spreader bar of the actuator.



The swivel on the left is the MTS249B swivel, which is 158.3 kg (349 lbs), while the swivel on the right is a 249NB swivel, which is 152.4 kg (336 lbs). Please note that these weights exclude the weight of the swivel base as the base is fastened to the steel frame and does not induce a force on the pipe.

With basic equilibrium equations and assuming the swivels are well oiled and provide negligible load support, the initial reaction at A is 362 lbs (vertical) and the initial reaction at B is 323 lbs (vertical).

$$\Sigma M_A = 0$$

$$(349)(4) - (336)(8) + (B_y)(4) = 0$$

$$B_y = 323\ lbs \uparrow$$

$$\uparrow \Sigma M_y = 0$$

$$A_y + 323 - 349 - 336 = 0$$

$$A_y = 362\ lbs \uparrow$$

To examine the induced stresses on the pipe from the swivels over the course of the test, we need to analyze test data. The frame has not been used for pipe testing yet, so the exact unintended loads and stresses induced on the pipe from the frame are not known.

6. Conclusion

The biaxial bending test presents some unique challenges, but becomes a significantly simpler design problem when working within laboratory constraints and following the design of traditional 4-point bending and axial tests. It is expected that there may be some additional unintended loads or other issues with the frame when it is used for testing. However, because so many elements of the frame are borrowed from other testing frames, we have some idea of how it should perform in testing. Overall, this frame will be extremely useful in future projects, particularly the ARPA-E pipe testing project, which has massive implications for rehabilitating American gas infrastructure.

7. References

Berty, Nicholas W., et al. Performance Assessment of IPVC Pipe and Couplings for Large Ground Movement. Center for Infrastructure, Energy, and Space Testing Civil, Environmental, and Architectural Engineering, 1 Mar. 22AD.

Dixon, Patrick G., et al. Development of a Testing and Analysis Framework for Validation of Rehabilitating Pipe-In-Pipe Technologies. CIEST, CEAE, 10 Apr. 2022.