

# Symposium on Pipe Rehabilitation Design

Sponsored by  
The Trenchless Technology Center (TTC) & The Pipe Rehabilitation Council (PRC)

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## Symposium Summary

Ray Sterling, Ph.D., P.E.

CETF Professor of Civil Engineering  
Director, Trenchless Technology Center

The Pipeline Rehabilitation Council has made a continuing effort over the past four years to address issues regarding the design and specification of liners to be installed in non-pressure buried pipes in North America. Taking the advantage of an American Society of Testing and Materials (ASTM) meeting in Dallas, the Pipe Rehabilitation Council (PRC) and the Trenchless Technology Center (TTC) co-hosted this special meeting to discuss the recent research results related to buckling of pipe liners under external pressure and the design loads expected to be carried by a liner when installed in a severely structurally deteriorated pipe.

The program was initiated and brought together by George McAlpine, Chairman of the PRC and President of Danby of North America, Inc. and I acted as the moderator for the event which took place on the afternoon of November 4, 2001.

The program consisted of two key presentations. The first by John Gumbel, Technical Director, Insituform Technologies, Winchester, U.K. and the second by George McAlpine. John Gumbel presented a paper entitled "New Approach to Design of Circular Liner Pipe to Resist External Hydrostatic Pressure" and George McAlpine presented a paper entitled "Rehabilitation of Fully Deteriorated Rigid Pipes by Flexible and Rigid Liners." After each presentation, a formal response and commentary to each presentation was made by David Hall, Assistant Professor of Mechanical Engineering at Louisiana Tech University and Ian Moore, Canada Research Chair of Infrastructure Engineering at Queen's University. The formal papers or handouts from the computer slide presentation for each presentation are included in this document. The meeting concluded with an open discussion of the issues raised during the session. The discussion was lively and constructive.

The presentations and discussions indicated that the approaches to the prediction of constrained liner buckling are converging but that a more rational approach needs to be taken to the design load parameters for the "fully deteriorated" condition.

John Gumbel's paper focused on the prediction of buckling behavior of close-fitting liners for use in gravity sewer pipes under hydrostatic loading caused by external groundwater pressures. In North America, the formula given in ASTM F1216 (1998) is most frequently used for the calculation of the critical buckling pressure for such liners. While this formula has served the industry and public well in allowing pipe rehabilitation projects to be safely designed, John Gumbel's paper shows that the formula was based on liner conditions quite different from those experienced by a close-fitting liner as it comes under load. To account for the enhancement of critical buckling pressure for a close-fitting liner over an unrestrained liner, a simple empirical "enhancement factor"  $K$  is included in the ASTM formula but this single enhancement factor results in significantly different factors of safety for different liner design parameters. There are, however, theoretical models that can predict non-linear behavior of restrained (close-fitting) liners and the paper shows that these can provide a much closer prediction of buckling behavior over a wide range of conditions and also can include the effects of ovality, annular gap and host pipe imperfections. Based on extensions by Boot (1998) to the theoretical developments made by Glock (1977), Gumbel shows how this theory can be developed into design charts or a spreadsheet based calculation approach that provides a better design prediction of liner behavior than the current formula.

The response by David Hall agreed that the model proposed by Gumbel does provide a reasonable design approach for close-fit liners and a significant improvement over what is currently used in ASTM F1216 but pointed out that there are other similar models that should be evaluated so that the most effective design approach is chosen. Hall set out a series of steps that could be used to accomplish this task. He also discussed the need to decide on whether one-lobe or two-lobe buckling should be used as the basis for the design equation and the need to be able to cover the full range of ovality, gap and imperfection that may be present in practical situations.

The response by Ian Moore also confirmed that the approach set out by Gumbel addresses the major issues with the ASTM F1216 approach. Moore supplemented the previous data presented with simulation results obtained by El Sawy and pointed out the need to consider the interaction effects of gap, ovality and imperfection. He concluded by concurring with the improvements suggested in the Gumbel approach. He found that the separation of imperfection effects into those that related to the host pipe (system imperfections) and those that related to the particular renovation technique (characteristic imperfections) was a useful concept in addressing the issue of imperfections in liner design. He indicated that the issue of the safety factor to be applied relative to one-lobe or two-lobe buckling may need further consideration.

George McAlpine's presentation focused on the issue of how to address the loads on a pipe liner when the host pipe is badly deteriorated – the "fully deteriorated" condition in ASTM F1216. He effectively pointed out the inconsistencies in the assumptions that a pipe was fully deteriorated but could nevertheless still be lined and explored what kinds of loadings a liner within the host pipe could be expected to be subject to. The ASTM approach to the design load is to consider the full soil load from the pipe to the surface – essentially ignoring the fact that the liner will be installed within a pipe that is still stable and the arching capability of a soil that has been in place for many years. In the case of relining an existing pipe, the potential soil-induced loads (as opposed to water pressure loads) that a liner placed within a non-collapsed pipe may experience

are more similar to those used in a tunnel support design approach than an open-cut buried pipe approach. McAlpine argued that the test data on liners subject to earth loads does not support buckling as a failure state. He pointed out the inconsistencies in the assumptions of buckling based on the Luscher/AWWA C950 approach and their divergence from field test results and the types of loadings that cause failure in linings in practice. He further argued that, if soil support required by buckling design exists, most rigid pipes would benefit little, structurally, from a liner. Liners add stiffness but are less influential than soil modulus in the overall stiffness of the liner-pipe-soil structure.

David Hall concurred with the difficulties with the current approach raised by McAlpine and felt that additional simulation would be helpful in studying the interaction of the liner with the deteriorated host pipe and the surrounding soil. The key in assessing behavior of a liner placed in a deteriorated host pipe is knowing the condition of the soil around the pipe and any future changes in surface loading. These issues may include whether voids are present, whether the soil is continuing to consolidate around the host pipe and whether future excavations will disturb the natural soil arching developed.

Ian Moore gave an extensive commentary and presentation on the issues raised by McAlpine's presentation and paper since this subject is the subject of current research by his group and also fits with his prior research experience. Moore concurred with McAlpine that that use of a buckling equation to represent failure of a liner under ground loading conditions is not appropriate since buckling (related to hoop compression of the liner) is more-or-less impossible within a deteriorated host pipe that tends to apply point loadings to the liner and does not provide a "following" uniform pressure as is the case in the groundwater loading scenario. Moore presented the results of his experimental work with cracked host pipes in a soil test cell and concluded that further tests for grouted or close-fitting liners is needed.

The discussion explored more details in some areas of the presentation as well as what the panelists felt was the expected changes in standards that would result from the recent research. It was clear from the papers and discussion that there is considerable convergence in the technical community on predicting the behavior of close-fitting liners under external water pressure. It was also clear that, although a new design standard has not yet been formally proposed, the design approach for the "fully-deteriorated condition" is not supported by theoretical or practical considerations. For both aspects of liner design, changes in current design standards in North America need to be implemented. It is expected that the first formal guidelines in North America to reflect these changes will be guidelines being developed by an ASCE Pipeline Infrastructure (PINS) Committee chaired by Jay Schrock.