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Alexis Ostapenko

Joseph A. Padula

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# Residual Strength of Offshore Structures After Damage

**Project Description for the 1985-86 Annual Report of Technology Assessment and Research Program for Offshore Minerals Operations**

by

Alexis Ostapenko

Joseph A. Padula

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# Residual Strength of Offshore Structures After Damage

Principal Investigator: Dr. A. Ostapenko
Department of Civil Engineering
Lehigh University
Bethlehem, PA 18015

Objective: To develop computer programs for analyzing the residual strength of individual members and of offshore platform subframes weakened by damage due to overload and/or by dents and distortions caused by ship impact or falling objects.

In addition to the operational and environmental loads, an offshore platform may be subjected to impact by ships or heavy falling objects. As a result, the platform capacity may be significantly impared by the dents or overall distortions caused by the impact on the bracing members or on legs.

Such damage to an offshore structure may have serious environmental consequences as well as jeopardize the safety of its crew. The goal of this research is to provide engineers with tools to assess the residual strength of damaged offshore structures.

It should be noted that damage to offshore structures occurs in somewhat more than isolated incidences. It has been reported that dents with a depth of 10% of the diameter or permanent deflection of 0.4% of the length of a member occur almost every two years in the North Sea[1], and there have been a total of 560 various accidents around the world between 1970 and 1981[2].

The ultimate problem addressed by this research is the following: Given a damaged structure, what is its capacity to withstand the loads to which it may be subjected? Is immediate evacuation of the structure necessary because of imminently expected overloads? Are immediate emergency repairs necessary? What magnitude of loads can the structure withstand before repairs or retrofitting are completed? What is prudent action in the event of an approaching storm?

## BACKGROUND

Several papers have addressed this problem in general and pointed out the urgent need for more research beyond what has been done until now.[3, 4, 5] It has been shown that concern for minimizing impact damage should probably be the primary consideration in design rather than a check of certain portions of the platform to verify that the residual strength would be sufficient to withstand moderate environmental overloading without an immediate need for evacuation or repairs.[6]

The philosophy of "damage design" and some conservative design guidelines for unstiffened bracing and leg members under the North Sea conditions were outlined by Donegan.[6]

Review of available publications indicates a need for research in a number of areas in order to be reasonably confident in designing offshore platforms for possible damage. [Sample References: [2, 7, 8, 9, 10, 11, 5, 12, 13, 14, 15, 16, 17, 18, 19, 20]]

Probably, the most significant omission in these publications is the lack of experimental work on tubular members fabricated by cold-rolling and welding, which is the usual method of fabrication for offshore platforms, and of the consideration of larger diameter-thickness ratios.

The work of the current project deals with the following topics:

- Tests on the "denting" behavior of large-diameter fabricated tubulars.
- Energy dissipation characteristics of damaged platform members and of portions of a platform.
- Axial behavior of <u>fabricated</u> tubular members with dents and/or out-of-straightness caused by local buckling or impact and having other than pin-ended support.
- <u>Practical</u> design methods for considering the deleterious effect of damage on member strength. Although some finite element computer programs have been developed or can be developed, they would be too complicated and expensive to use and, thus, are hardly suitable for engineering practice.

This research is planned to consist of the following four approximately sequential phases:

1. Experimental study of the denting behavior of fabricated tubular columns.
2. Analytical work and development of computer programs.
3. Additional tests on members and subassemblages.
4. Development of simplified analytical tools suitable for use by engineers in analyzing damaged offshore structures.

## PHASE 1 -- TESTING OF TWO DENTED SPECIMENS

The initial phase of the project consisted of performing tests on two tubular specimens which had been saved from a previous research project.[21] The specimens were originally fabricated by cold-rolling flat plates into a cylindrical shape and welding the seam, as is common in the production of offshore platform members. In the previous project the specimens were subjected to axial compression till they developed local buckles. For the purpose of this present research, the specimens were modified by removing the portions with local buckles and rewelding the end rings. The two specimens had diameters of 40 and 60 inches and diameter-to-wall thickness ratios (D/t) of 151 and 227, respectively. The lengths of the specimens were reduced from 10 feet to 8 and 7 feet, respectively.

After refabrication, a controlled indentation was introduced into each specimen to simulate the damage due to impact. A 7-inch wide wide-flange beam was placed between the machine head and the specimen for making the indentation. The arrangement, with the beam positioned transversely at mid-length of the specimen, is shown in Fig. 1. Incremental loading was then applied until the indentation reached a predetermined value. Internal bracing in the form of wooden or metal struts was placed inside the specimens during the process to localize the effect of the indentation. The final residual deformation was a flattened area 7 inches wide, perpendicular to the longitudinal axis of the member and with the depth of 1.1 and 3.3 inches for the 40- and 60-inch specimens, respectively. Measurements were made so that the deformational response and energy dissipation of each specimen could be analyzed.

The next step was to determine the effect of the indentation on the axial behavior and strength. Each specimen was subjected to an axial load to failure. Flat-to-flat end conditions were imposed by the test set-up as shown in Fig. 2. The failure mechanism of the 40-inch diameter specimen was the formation of a ring bulge at one end of the specimen. As the ring bulge developed, the load started dropping off, and the test was stopped before the deformtions were too large. It is hoped that the specimen may be retested later with the ends having fixed-free conditions in order to duplicate the behavior of a long column.[22]

The failure mechanism of the 60-inch diameter specimen was the formation of multiple buckles in a checkerboard pattern over the surface and an immediate drop-off of the load.

The results of the axial load tests showed that the 40-inch diameter specimen showed virtually no reduction in stiffness or ultimate strength due to the indentation of the member. For the 60-inch specimen, the stiffness was also unchanged, but the ultimate strength was somewhat reduced.

The rather unexpected lack of the reduction in strength due to the indentation can be attributed to the end conditions of the specimens during testing. (Numerical analysis and possible retesting of the 40-inch specimen should provide verification of this assumption.)

## PHASE 2 -- DEVELOPMENT OF COMPUTER PROGRAMS AND GENERATION OF DATA BASE

The second task of the research project is to develop computer programs for analyzing the energy dissipation characteristics and the behavior of tubular members subjected to denting and overall deformation caused by transverse (impact) loads and to axial compression. A method will also be developed to predict the residual strength and behavior of frames (platform subassemblages) containing a damaged member. The algorithms will take into account plastification and large deformations of the members. Due to the complexity of this problem, the computer programs will be research oriented and not practically useful in engineering design.

The results of the experimental work in the first phase of the project and of other tests reported in literature will be used to calibrate these computer programs.

Once the computer programs become operational, they will be used to generate numerical data base for conducting later parametric studies of the interaction of various geometrical and material parameters.

## PHASE 3 -- TESTS ON MEMBERS AND SUBASSEMBLAGES

Additional tests will be designed to further verify and improve the analytical methods and computer programs.

The details will depend on the outcome of the first two phases of the project. Tentatively, tests on long damaged members with restrained ends and on a subassemblage are considered.

This testing will complete the experimental portion of the project.

## PHASE 4 -- PARAMETRIC STUDY AND DEVELOPMENT OF DESIGN PROCEDURES

The final task of the project will be to formulate simplified analysis and design procedures suitable for enginering practice.

The formulation will involve a thorough parametric study of the experimental and theoretical data generated in the previous phases of the research, as well as supplemented by additional computations. Some of the variable parameters used in the parametric study will be the yield stress, diameter to wall thickness ratio, length to radius of gyration ratio, and end restraints of the member. The object parameters will be the energy dissipation characteristics and the residual strength of members and frames after damage.

Functional relationships will be formulated by performing multi-variable regression analysis using the methodology successfully employed in the past for plates and stiffened plates.[23, 24].

The results will then be formulated for use on a microcomputer, programmable calculator, or, perhaps, as charts and nomographs. In this form they will be practically useful to engineers in analyzing the strength of damaged offshore structures.

## REFERENCES


1. Taby, J., and Moan, T., "Collapse and Residual Strength of Damaged Tubular Members," in *Behaviour of Offshore Structures,* Elsevier Science Publishers B.V., Amsterdam, 1985, pp. 395-408.

2. Ellinas, C.P., and Valsgard, S., "Collision and Damage of Offshore Structures: A State-of-the-Art," *Proceedings of the Fourth International Offshore Mechanics and Arctic Engineering Symposium, Vol. 2,* American Society of Mechanical Engineers, New York, February 1985, pp. 475-495, (Symposium held in Dallas, TX, on February 17-21, 1985)

3. Foss, G., "Research in Norway on the Stability of Circular Tubes," *Proceedings of the Annual Technical Session, held March 30-31, 1982, in New Orleans,* Structural Stability Research Council, Bethlehem, PA, March 1982, pp. 45-70.

4. Harding, J.E., Onoufriou, A., and Tsang, S.K., "Collisions - What is the Danger to

Offshore Rigs?," *Journal of Constructional Steel Research,* Vol. 3, No. 2, 1983, pp. 31-38.

5. Richards, D.M., and Andronicou, A., "Residual Strength of Dented Tubulars: Impact Energy Correlation," *Proceedings of the Fourth International Offshore Mechanics and Arctic Engineering Symposium, Vol. 2,* American Society of Mechanical Engineers, New York, February 1985, pp. 518-527, (Symposium held in Dallas, TX, on February 17-21, 1985)

6. Donegan, E.M., "Appraisal of Accidental Impact Loadings on Steel Piled North Sea Structures," *Proceedings of the 14-th OTC,* Offshore Technology Conference, Houston, May 1982, pp. (Vol.1)321-328, (Paper 4193)

7. Foss, G., and Edvardsen, G., "Energy Absorbtion during Ship Impact on Offshore Steel Structures," *Proceedings of the 14-th OTC,* Offshore Technology Conference, Houston, May 1982, pp. (Vol.1)625-634, (Paper 4217)

8. Grimm, D.F., and Ostapenko, A., "Local Buckling of Steel Tubular Columns," *Proceedings,* Structural Stability Research Council, Bethlehem, PA, 1982, pp. 25-28.

9. Ostapenko, A., "Local Buckling of Welded Tubular Columns," *Proceedings of the International Colloquium on Stability of Structures Under Static and Dynamic Loads,* American Society of Civil Engineers, New York, May 1977, pp. 367-374, (Colloquium held in Washington, D.C., on May 17-19, 1977)

10. Ostapenko, A., "Local Buckling Tests on Tubular Columns (36-50-100 ksi)," *Proceedings,* Structural Stability Research Council, Bethlehem, Pa., April 1979, pp. 46-49, Technical Meeting held on April 21-25, 1979, in Pittsburgh

11. Popov, E.P., Zayas, V.A., and Mahin, S.A., "Cyclic Inelastic Buckling of Thin Tubular Columns," *Journal of the Structural Division, ASCE,* Vol. 105, No. ST11, November 1979, pp. 2261-2277.

12. Schippers, J., Boonstra, H., and Koot, P., "Replacement of a Damaged Diagonal Bracing in a Semisubmersible Drilling Rig," *Proceedings of the 14-th OTC,* Offshore Technology Conference, Houston, May 1982, pp. (Vol.1)569-579, (Paper 4213)

13. Sherman, D.R., "Inelastic Local Buckling of Circular Tubes," *Offshore Structures Engineering III --- Buckling of Shells in Offshore Structures,* Harding, J.E., Dowling, P.J., and Agelidis, N., ed., Gulf Publishing Co. (also, Granada Publishing), Houston, London, Paris, Tokyo, 1982, pp. 365-392, (Proceedings of the conference held in April 1981 at Imperial College, London)

14. Smith, C.S., and Dow, R.S., "Residual Strength of Damaged Steel Ships and Offshore Structures," *The Journal of Constructional Steel Research,* Vol. 1, No. 4, Sept 1981, pp. 2-15, Published by Granada

15. Smith, C.S., "Strength and Stiffness of Damaged Tubular Beam Columns," *Offshore Structures Engineering III --- Buckling of Shells in Offshore Structures,* Harding, J.E., Dowling, P.J., and Agelidis, N., ed., Gulf Publishing Co. (also, Granada Publishing), Houston, London, Paris, Tokyo, 1982, pp. 1-23, (Proceedings of the conference held in April 1981 at Imperial College, London)

16. Soreide, T.H., and Amdahl, J., "Deformation Characteristics of Tubular Members with Reference to Impact Loads from Collision and Dropped Objects," *Norwegian Maritime Research,* Vol. 10, No. 2, 1982, pp. 3-12.

17. Taby, J., Moan, T., and Rashed, S.M.H., "Theoretical and Experimental Study of the Behaviour of Damaged Tubular Members in Offshore Structures," *Norwegian Maritime Research,* Vol. 9, No. 2, 1981, pp. 26-33.

18. Toma, S., Chen, W.F., "Post-Buckling Behavior of Tubular Beam-Columns," *ASCE Journal of Structural Engineering,* Vol. 109, No. 8, August 1983, pp. 1918-1932.

19. Ueda, Y., and Rashed, S.M.H., "Behavior of Damaged Tubular Structural Members," *Proceedings of the Fourth International Offshore Mechanics and Arctic Engineering Symposium, Vol. 2,* American Society of Mechanical Engineers, New York, February 1985, pp. 528-536, (Symposium held in Dallas, TX, on February 17-21, 1985)

20. Zayas, V.A., Mahin, S.A., and Popov, E.P., "Cyclic Inelastic Behavior of Steel Offshore Structures," Tech. report UCB/EERC-80/27, University of California, Earthquake Engineering Research Center, August 1980.

21. Ostapenko, A., and Grimm, D.F., "Local Buckling of Cylindrical Tubular Columns Made of A-36 Steel," Fritz Engineering Laboratory Report No. 450.7, Lehigh University, February 1980.

22. Salley, M.F., "Local Buckling of Steel Tubular Columns and the Effect of End Conditions," Master's thesis, Lehigh University, 1981, (M.S. Thesis supervised by A. Ostapenko)

23. Ostapenko, A., Surahman, A., "Axial Behavior of Longitudinally Stiffened Plates," *Stability of Metal Structures - Preliminary Report,* CTICM, Paris, November 1983, pp. 291-303, (Paris Session, November 16-17, 1983)

24. Ostapenko, A., "Computational Model for Load-Shortening of Plates," *Proceedings of Annual Technical Meeting, held on April 15-17, 1985, in Cleveland,* Structural Stability Research Council, 1985.

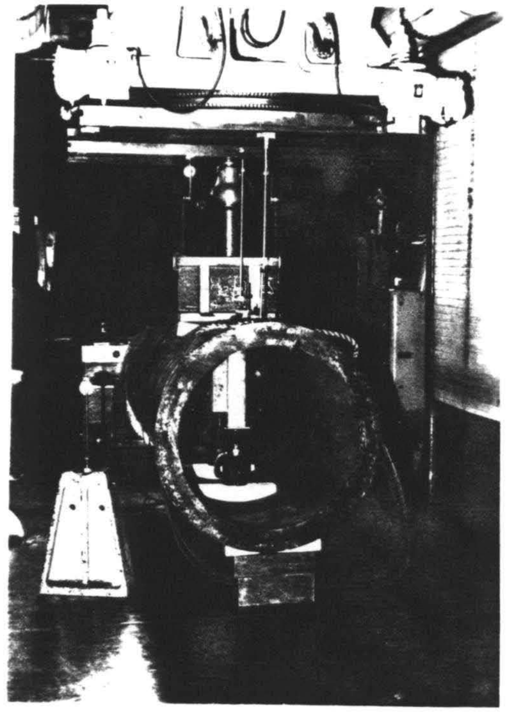

**Figure 1:** Set-Up for Making Indentation in 40-inch Diameter Specimen

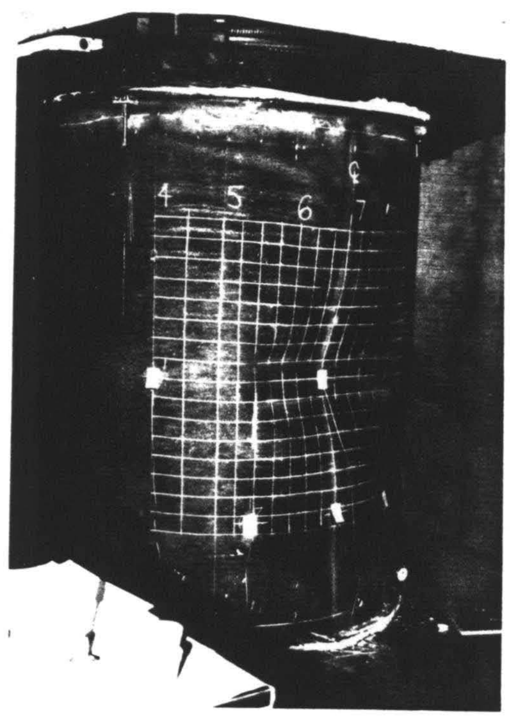


**Figure 2:** Axial Test on 60-inch Diameter Specimen