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# Simulation of the effect of an annular inclusion on stress concentration near an elongated elliptical opening in a spherical shell

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Shell structures are widely used in various branches of technology and industry due to a combination of a high strength and a relatively light weight. In the majority of cases, actual structures have openings for manufacturing or design reasons, thus leading to a sharp increase in local stresses and, as a result, to a decrease in the strength and reliability of the structure as a whole. That is why reducing stress concentration in thin-walled structural elements is an important and topical problem in deformable body mechanics. This paper presents the results of a computer simulation and finite-element analysis of the stress and strain field of a thin-walled spherical shell with an elongated elliptical opening and an annular inclusion that surrounds the opening at a certain distance therefrom. The effect of the geometrical and mechanical parameters of the inclusion and its distance from the opening contour on the concentration of the stress and strain field parameters of the shell is studied. The stress and strain intensity distribution in the local stress concentration zones is obtained.

It is shown that a rigid annular inclusion located at a certain distance from an opening allows one to reduce the stress concentration factor by nearly 27 percent with a proportional decrease in strain intensity in the vicinity of the opening.

The elliptical opening elongation degree greatly affects the concentration of the stress and strain field parameters. If an opening is reinforced with a rigid annular inclusion immediately along its contour, the stress intensity in its vicinity increases, while the strain intensity decreases. The numerical calculations conducted show that surrounding an opening with a rigid annular inclusion located remotely therefrom reduces both the stress and the strain intensity in the vicinity of the opening.  If an opening is reinforced immediately along its contour, a decrease in the maximum strain intensity is somewhat greater in comparison with the case where the rigid annual inclusion surrounding the opening is located at some distance therefrom.

The use of specially selected and located reinforcements of elongated elliptical openings in spherical shells allows one to control the stress and strain intensity distribution and magnitude in the zones of local concentration of their stress and strain field parameters.

1. Pogorelov V. I. Structural Mechanics of Thin-Walled Structures. Saint Petersburg, 2007. 528 pp. (in Russian).

2. Abovsky N. P., Andreev N. P., Deruga A. P. Variational Principles of Elasticity and Shell Theory. Moscow, 1978. 228 pp. (in Russian)

3. Avdotin A. S., Figurovsky V. F. Flying Vehicle Strength Analysis. Moscow, 1985. 39 pp. (in Russian).

4. Arzamasov B. N., Solov'eva T. V., Gerasimov S. A. Handbook on Structural Materials. Moscow, 2005. 60 pp. (in Russian).

5. Hart E. L., Vasylevskyi K. O. Computer simulation of a shallow shell with circular openings in tension. Problems in Computational Mechanics and Structural Strength. Dnipropetrovsk, 2014. Iss. 22. Pp. 57-66. (in Ukrainian).

6. Peterson R. Stress Concentration Factors. Moscow, 1977. 227 pp. (in Russian).

7. Hart E. L., Terokhin B. I. Computer simulation of the stress-strain state of the plate with circular hole and functionally graded inclusion. Journal of Optimization, Differential Equations and their Applications. 2021. V. 29. Iss.1. Pp. 42-53.
https://doi.org/10.15421/142103

8. Hart E. L., Panchenko S. V. Numerical analysis of the stress and strain field of a plate with a rectangular opening reinforced with straps. Problems in Computational Mechanics and Structural Strength. Dnipropetrovsk, 2015. Iss. 2. Pp. 35-47. (in Russian).

9. Hudramovich V. S., Hart E. L., Marchenko O. A. Effect of the shape of reinforcements on the stress and strain field of a cylindrical shell with elongated rectangular openings. Problems in Computational Mechanics and Structural Strength. Dnipro, 2017. Iss. 27. Pp. 52-64. (in Ukrainian).

10. Hudramovich V. S., Hart E. L., Panchenko S. V. Stress and strain field of plates with reinforced rectangular openings variously orientated relative to the direction of the tensile force. Teh. Meh. 2018. No. 4. Pp. 82-89. (in Russian).
https://doi.org/10.15407/itm2018.04.082

11. Gudramovich V. S., Gart É. L., Strunin K. . Modeling of the behavior of plane-deformable elastic media with elongated elliptic and rectangular inclusions. Materials Science. 2017. V. 52. Iss. 6. p. 768-774.
https://doi.org/10.1007/s11003-017-0020-z

12. Hudramovich V. S., Hart E. L., Marchenko O. A. Reinforcing inclusion effect on the stress concentration within the spherical shell having an elliptical opening under uniform internal pressure. Strength Mater. 2021. V. 52. No. 6. Pp. 832-842.
https://doi.org/10.1007/s11223-021-00237-7

13. Timoshenko S. P., Lessels J. Applied Elasticity Theory. Leningrad, 1931. 394 pp. (in Russian).

14. Savin G. N. Stress Distribution in the Vicinity of Openings. Kiev, 1968. 888 pp. (in Russian).

15. Guz A. N., Chernyshenko I. S., Chekhov V. N. et al. Shell Analysis Methods. In 5 volumes. V. 1. Theory of Opening-Weakened Thin Shells. Kiev, 1980. 636 pp. (in Russian).

16. Mulyar V. P. On the stress distribution in a spherical shell with an off-center curvilinear hole. International Applied Mechanics. 2006. V. 42. Iss. 1. Pp. 98-102.
https://doi.org/10.1007/s10778-006-0063-6

17. Stepanyan M. N. The point moment at an arbitrary point of an elastic plane weakened by an elliptical hole. J. Appl. Math. Mech. 1999. V. 63. Iss. 2. Pp. 333-335.
https://doi.org/10.1016/S0021-8928(99)00044-1

18. Dovbnya E. N., Krupko N. A. Effect of a circular opening on the stress field of a shell of arbitrary Gaussian curvature. Bulletin of Donetsk University. 2014. Iss. 1. Pp. 108-125. (in Russian).
https://doi.org/10.15593/2224-9893/2014.1.05

19. Dovbnya K. M., Grygorchuk Yu. V. Stress field of a double-curvature shell with a crack in bending. Problems in Computational Mechanics and Structural Strength. Dnipropetrovsk, 2012. Iss. 19. Pp. 112-116. (in Ukrainian).

20. Guz A. N., Storozhuk E. A., Chernyshenko I. S., Inelastic deformation of flexible spherical shells with two circular openings. Int. Appl. Mech. 2004. V. 40. Iss. 6. Pp. 672-678.
https://doi.org/10.1023/B:INAM.0000041395.63200.aa

21. Storozhuk E. A., Chernyshenko I. S. Physically and geometrically nonlinear deformation of spherical shells with an elliptic hole. Int. Appl. Mech. 2005. V. 41. Iss. 6. Pp. 666-674.
https://doi.org/10.1007/s10778-005-0134-0

22. Marchenko . ., Hart E. L., Hudramovich V. S. Stress concentration in the vicinity of an elliptical opening in a spherical shell in the presence of annular inclusion Problems in Computational Mechanics and Structural Strength. Dnipro, 2021. Iss. 33. Pp. 98-113. (in Ukrainian).

23. Hudramovich V. S., Hart E. L., Marchenko O. A. Reinforcing inclusion effect on the stress concentration within the spherical shell having an elliptical opening under uniform internal pressure. Strength Mater. 2021. V. 52. No. 6. Pp. 832-842.
https://doi.org/10.1007/s11223-021-00237-7

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24. Evzerov I. D., Zdorenko V. S. Convergence of plane finite elements of a thin shell. Structural Mechanics and Analysis of Constructions. 1984. No. 1. Pp. 35-40. (in Russian).