

WELDED RIBBED MANHOLE COVER – FEM ANALYSIS AND PROTOTYPE TESTING

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DOI: 10.17973/MMSJ.2021_03_2021005

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In this paper, in order to achieve the required properties, several numerical simulations of pressure loading of the welded manhole cover are performed. The analysis of displacement and stress using the finite element method in the software NX Siemens 12 were conducted. Verification of numerical results was done by performing prototype testing consisting of the permanent deformation test and a loading capacity test. The loading capacity test was performed until the fracture occurred. The main goal of the paper is to determine the behaviour of the manhole cover under pressure load. The outcome of the analysis will be used for the design development of similar manhole covers.

KEYWORDS

Manhole cover, ribbed – welded construction, pressure loaded, finite element method

1 INTRODUCTION

The analysed manhole cover must be able to rest the greatest load defined in the standard ČSN EN 124 – 1. This norm defines total 6 load groups according to the use of a manhole. From low load caused by pedestrians walking and cyclists riding over it to heavy loads on an airfield, where heavy duty vehicles or even airplanes can cross over this cover.

Steel and aluminium manhole covers must fulfil the standard ČSN EN 124 – 3, which describes the requirements for vehicular and pedestrian areas. The structural steel S235JR and S355J2 was chosen. Common parameters for steel are Young's modulus $E = 210\,000$ MPa and Poisson's ratio $\mu = 0.3$. According to ČSN EN 10025-2 mechanical properties are following, for steel S235JR Yield strength $R_e = 235$ MPa, minimum tensile strength $R_m = 360$ MPa. For steel S355J2 Yield strength $R_e = 355$ MPa, minimum tensile strength $R_m = 470$ MPa.

There are two conflicting requirements for the design of the manhole cover. The first requirement is the resistance to high pressure loading. The second requirement emphasis its low mass so it is easy to lift. These requirements can be achieved by ribbing the cover. The verification of the suitability of designed ribbing was analysed by simple simulation. This simulation was based on the finite element method. Unlike the final simulation, this has a linear character. The material was entered until the yield point and friction was neglected. This simulation was constantly changing according to design changes. It was very time consuming to find ideal ribbing. After finding suitable ribbing, the structure was next analysed. Furthermore, a more detailed analysis and testing on a prototype was performed.

More detailed simulation is more time consuming and it is not possible to afford it in a short time for design of new cover. For this reason, the conclusion of this work is important for the design of similar covers. This simulation

considers the plasticity of the material and friction in contacts. It has nonlinear character. The main goal of this simulation is to precisely be determined weak and critical points of the cover.

For the application and certification of the manhole cover it is necessary to resist loads significantly more than the operating load. Testing pressure load is 90 tonnes. The expected operating load is approximately one third. Two tests are performed in succession. First, the permanent deformation test is tested, followed immediately by the loading capacity test. The permanent deformation test consists of five cycles and a test load is 60 tonnes. The cycles must follow each other immediately without significant delay. During the test and at the end, the cover must be without visible cracks. At the end of the load, the deflection height in the geometric centre of the cover is checked. The measured height of the deflection must be less than allowed by the standard. This test is immediately followed by a loading capacity test. The loading capacity test can be performed at a pressure load of 90 tons or until the manhole cover is destroyed. The cover must withstand a load of 90 t without visible cracks. Pressure load resistance of 90 tonnes allows the cover to be included in all groups according the standard ČSN EN 124 – 1.

2 DESCRIPTION OF THE DESIGNED STRUCTURE

The manhole cover is one part of the manhole. Another important part of the manhole is the frame. The frame and the cover are the most important parts, these parts determine the size, shape, and location for other parts. Other parts serve as sealing and locking. All parts of the manhole part are in the Figure 1.

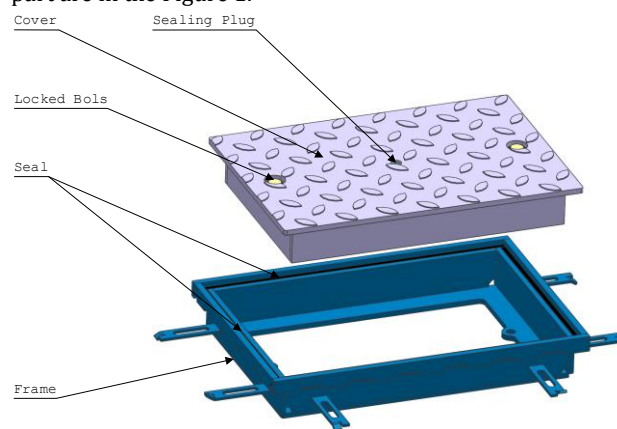


Figure 1. Manhole

The main requirements for the manhole cover are the resistance to pressure load of 90 tonnes and emphasis to its lightweight design. The maximum allowed weight of the cover is 50 kilograms. This maximum allowed mass guarantees easy lifting for the operators. The cover can be seen in the Figure 1. above. The upper surface of the plate must ensure anti-slip resistance, it is ensured by teardrop-shaped protrusions. There is a hole in the middle of the cover for lifting. The hole is sealed by sealing plug. There are also two holes for the locking cover. By inserting the two screws through these holes and bolting to the frame is the manhole blocked. Reinforcing ribs are under the top plate which significantly helping to increase the stiffness of the structure. The stress and deformation of the ribs will be analysed.

The cover is placed in the frame. The frame is fixed by concreting it into the ground. The frame can be seen in the Figure 1. at the very bottom layer. The threaded holes for two bolts are on the bottom plate. The frame has a groove in the upper part for the seal. A seal with square cross section

is inserted into this groove around the entire perimeter. The seal must prevent water from entering to the chamber. For a better connection of the frame with the concrete there are lugs around the perimeter of the manhole frame. The basic dimensions of the manhole cover for analysis are in the Figure 2.

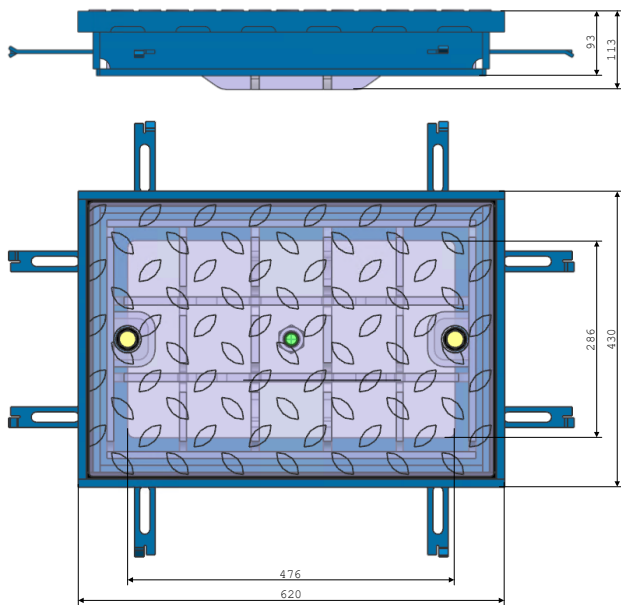


Figure 2. Basic Dimensions

3 PREPARATION OF THE SIMULATION AND THE PROTOTYPE TESTING

This part deals with the preparation of the simulation and the testing of the prototype. The description of the preparations is in the order in which the analysis was performed. The simulation was performed first because it is less time-consuming and cheaper.

The boundary conditions were set to resemble as much as possible prototyping test. It was clear how the hatch would be placed. Everything had to be set according to the standard ČSN EN 124 – 1. The cover is tested together with the frame. The manhole was not fitted with the sealing and the locking parts during the prototype testing therefore they will not be simulated in the SW simulation neither. The cover is placed in the frame. The frame was placed on profiles. The tool for the load distribution was placed in the geometric centre of the manhole. Prototype testing is seen in the Figure 3. It will be tested on a spindle press.



Figure 3. Preparation of the experiment

The manhole is symmetrical according to two planes. The symmetry enabled a considerable simplification of the

simulation model. The whole test can be simulated as one quarter. The calculating of one quarter model is faster. The calculation speed was not used for the cover analysis. A more detailed approach was chosen for the analysis of the cover. The model was described by smaller mesh elements. This again extended the calculation over time. The simulation model can be seen in the Figure 4. For better orientation in the model, a coordinate system is placed in the plane section.

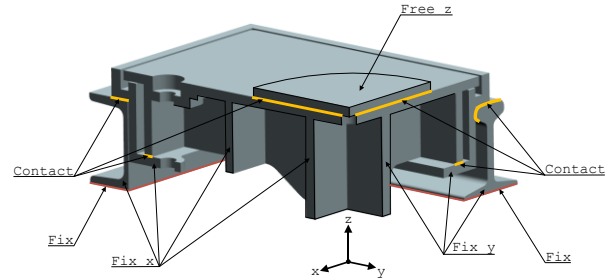


Figure 4. Boundary conditions

Displacement in normal directions is prevented in the section planes, this prevention is described in the Figure 4 as Fix x and Fix y. Fix x means to prevent displacement in the x-axis direction and correspondingly the y-axis direction. All degrees of freedom are removed at the bottom of the profiles, it is described as Fix and the surface is marked by red colour. All degrees of freedom were removed from the tool except the z axis. The displacement in the z-axis direction is described as Free Z. This simulation contains a total of 3 contacts of parts. The first is the contact of the tool with the manhole cover. The second is the contact of the cover with the frame. The third is the contact of the frame with the supporting profiles. The coefficient of friction in the first contact is 0.3. It considers the location of the anti-slip measure between the tool and the cover. In other cases, the coefficient of friction is steel against steel and it is 0.1.

The next section describes meshing of the model. Great emphasis is placed on the quality and size of the elements in this simulation. Small construction details and the anti-slip texture on the top plate of the cover were neglected, these details have a little effect on the simulation. The used mesh can be seen in the

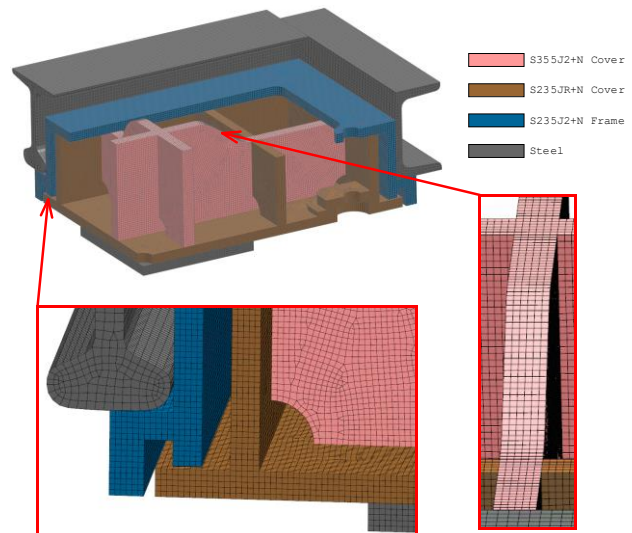


Figure 5.

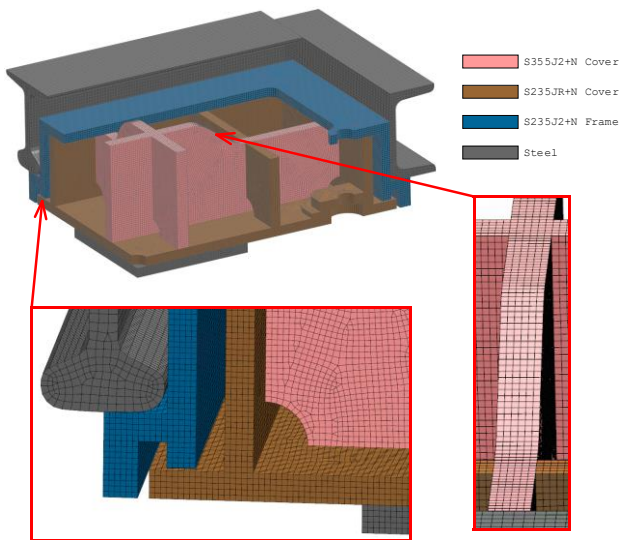


Figure 5. Model mesh

A mesh with a Bricks element without an intermediate node was used throughout the simulation. The mesh is called as CHEXA (8) in the software NX Siemens. A total of 4 mesh groups were created which are visible in the

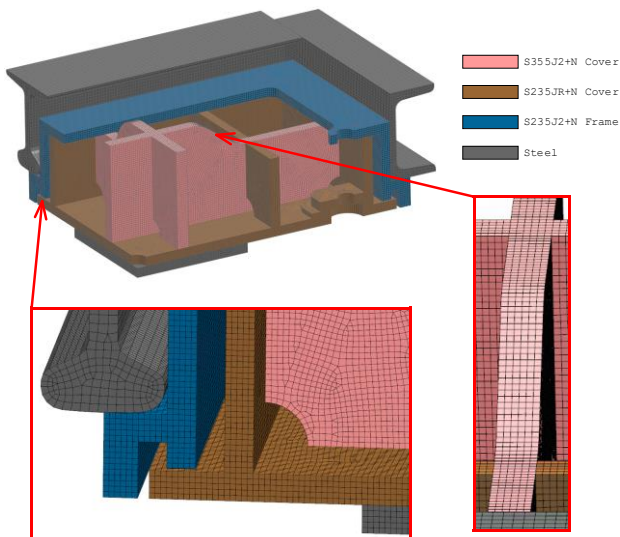


Figure 5, the individual groups are named as material + part. Material is named after the designation of steel a European standard was used. In terms of material properties, they are meshing S235J2+N Cover and S235J2+N Frame same. The division into these two groups is only to clarify the work. The cover is made of two steels. The main ribs are made of steel S355J2+N. The main rib is the rib that carries a substantial part of the loading. Less important parts of the cover were made of steel S235J2+N. For these two steels, the strength was given by a tensile diagram. The values of the tensile diagram were determined on standardized samples. For the other parts, the material was not specified by the tensile diagram. Steel was used with unspecified parameters. This steel is described by Young's modulus and Poisson's ratio. It includes a tool and a frame.

4 PERMANENT DEFORMATION TEST

The purpose of this test is to determine how cyclic loading is deforming the construction. This is evaluated by measuring the deflection of the manhole. The deflection measurement is performed in the geometric centre of the manhole. It is necessary to observe the surface of the manhole construction for possible cracks, the cracks must not occur during testing. The test load is 60 tonnes. It is two-thirds of

the load capacity test. This test was repeated by five times. The loading speed is 3 KN/sec. The test is performed by loading and unloading the manhole at the test speed without significant delay.

The simulation was performed in the same way as the test is defined in the standard ČSN EN 124 – 1. This was followed by the evaluation of the deflection. Displacement in the z-axis of the cover can be seen in the Figure 6.

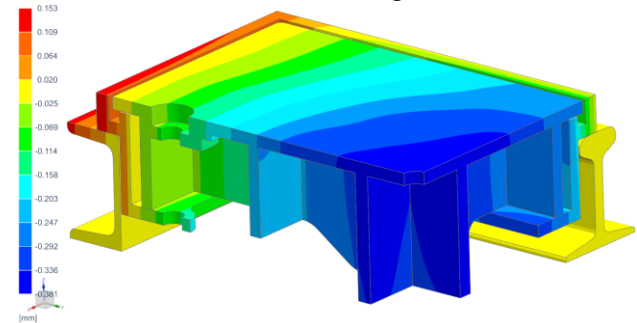


Figure 6. Displacement in the axis Z

There is a hole in the centre of the manhole cover. The deflection is measured as close as possible to the centre. Assessment of the distance from the geometric centre and deflection performed by a state testing laboratory. The maximum displacement in the z axis is located near the geometric centre, the displacement values are displayed in the scale in the Figure 6. The maximum value was compared with the values measured on prototype testing. Prototype testing was performed on three prototypes. The values from the simulation testing of the prototype can be seen in Table 1.

Displacement [mm]		
Simulation	Sample	
0.381	No. 1	0.340
	No. 2	0.410
	No. 3	0.380
	Average	0.380

Table 1. Displacements comparison

Prototype testing outcome values were averaged. The difference between this average value and the value from the simulation is minimal. The simulation well described prototype testing.

5 LOAD CAPACITY TEST

This test follows immediately after the permanent deformation test. The load was 90 tons which acted constantly for 30 seconds. Again, it is desirable that no cracks occur in the manhole construction.

The task of the simulation is to find weak and critical places of manhole. Stress and strain are used as two indicators for this evaluation. Result of the stress analysis show values and location of stress in the manhole, this value cannot exceed the allowed value of 235 MPa. Second indicator is the strain, shows degree of deformation and location in the manhole.

Stress

The first indicator, stress, was used for finding a weak and a critical place in the construction of the manhole. The critical place is a place with stress above the yield point of the material. The weak place is then the place where the stress value approaches the yield point of the material. In the Figure 7, it is possible to see the stress distribution in the manhole. On the left is a view from above on the manhole

and on the right is view from bottom. In the Figure 7 there is the area on the right with the highest stress highlighted. This area was zoomed and displayed at the bottom of the Figure 7. However, the critical place is still not well distinguishable from other places.

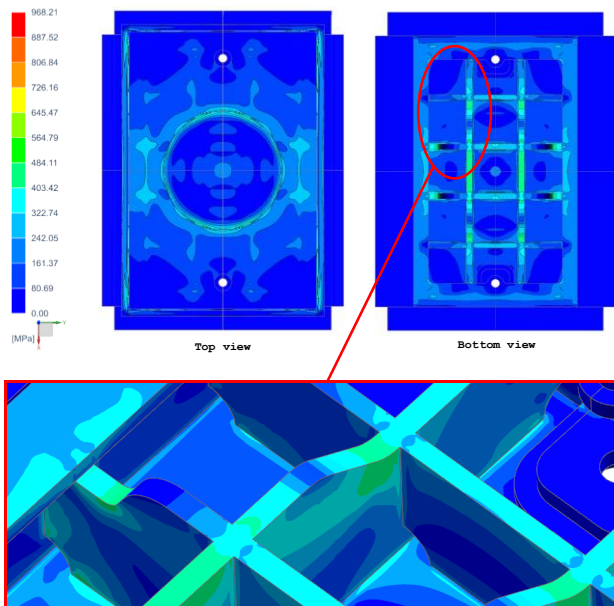


Figure 7. Stress distribution

Strain

The critical place was not clearly discernible from the stress result therefore will be used strain result. The result of this analysis can be seen in the Figure 8.

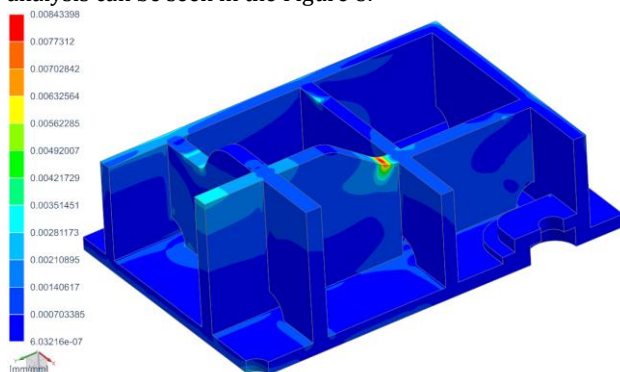


Figure 8. Strain

The Figure 8 clearly shows where the greatest deformations occur. There is a red area located in the radius of the longitudinal rib. It has been verified that the deformation decreases significantly with increasing radius. The figures shows a significantly bigger radius. In the first construction it was small. This finding will be important for the design of future covers. However, despite the increase in radius, there is considerable deformation. It will depend on how other of the ribs will deform. The goal is to design the cover that will deform as evenly as possible.

Destruction of the cover during the test

One of the three samples has been tested to destruction. The destruction does not mean that the covers do not pass the test. If the manhole resists 90 tons for 30 seconds, the test is successful. The further loading is due to the analysis week and critical location. The manhole may resist the tested load and it may not show these places at all. The deformations at higher loads can identify these places

Destruction of the cover occurred at the site revealed by the simulation – Figure 7 and Figure 8. The destruction of the

prototype can be seen in the Figure 9. There is a crack detail at the bottom of the image Figure 9.

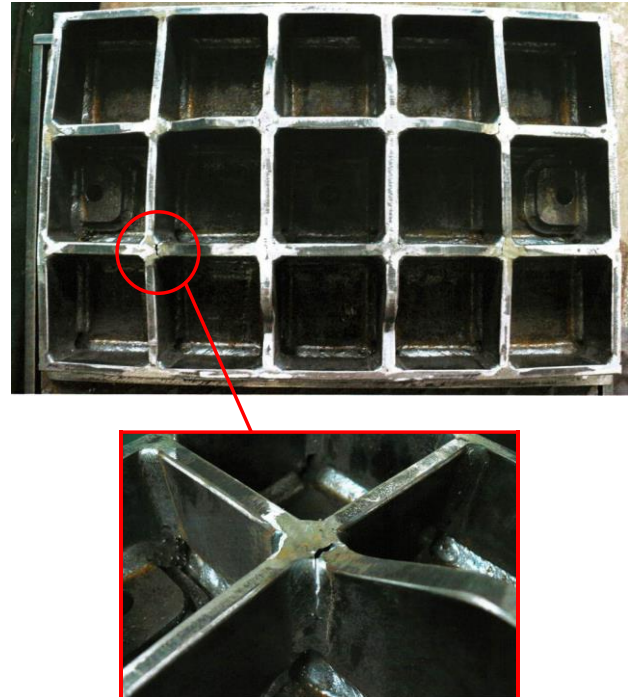


Figure 9. Location of destruction with the detail of crack

The crack on the prototype is in the radius of the longitudinal rib as in the simulation. The crack leads through the rib and the weld. This crack occurred under load 1 801 kN. Although the welds were not modelling in the simulation, they can be neglected with perfect welding. However, the crack occurred in the radius.

6 CONCLUSION

The results of the manhole FEM analysis were in conformity with the outcomes of the prototype testing. The manhole resists the pressure load without any problems, and it passed the test. The designed manhole is capable of resisting twice the load. It is therefore possible to allow possible imperfection in production, especially the execution of welds. A more detailed simulation found the weak and critical places very well. The results of stress and strain distributions were used to find locations. The simulation predicted the location of the crack and the experiment confirmed it. The simulation settings can be considered successful. The design advices were discovered during the analysis. They will certainly be used for the design of future manholes.

ACKNOWLEDGMENTS

This paper has been prepared under project 'Research of additive technologies for future usage in mechanical engineering - RTI plus', CZ.02.1.01/0.0/0.0/18_069/0010040 of the Pre-application research for ITI of the Ministry of Education of the Czech Republic aimed at supporting research, development and education.

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