INVESTIGATION OF STRUCTURE OF GASHOLDER WITH 5000 m^3 CAPACITY, DAMAGED DURING EXPLOITATION

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Abstract: *Cylindrical steel gasholder with initial capacity of 3000 m^3 is in service from 80th years of 20 century. After 10 years exploitation it has been reconstructed from "wet" to "dry" type and the capacity is increased to 5000 m^3.*

A few weeks after reconstruction, filled with gas to 60 ÷ 70 % of working volume gasholder, stops to work. It has been listen loud thunder and internal ceiling stepped on the bottom. During inspection has been established that supporting grating is damaged, membrane is punctured and bricks on moving ceiling are dislocated. Additional exploitation was impossible.

1. INTRODUCTION

New technologies and materials, introduced in gas industry, bring the opportunity for considerable reduction of exploitation expenses, improving the gas product storage and making longer the exploitation period. In the same time the insufficient practical experience in the building and exploitation of new equipment and underestimation of its particularity in working conditions shall create dangerous risk as the case of failure, surveyed by us, in PCOB – Kubratovo, during 2007, shows.

2. GENERAL DATAS

The gasholder, object of this report has been designed and built initially as "wet" with V=3000 m^3 capacity, together with another one neighboring with the same dimensions. Basic projects of the gas holders are Russian, typical, used the wide spread technology. The gasholders have been constructed in the beginning of the 80 years by the Bulgarian workers and have been used nearly 10 years.

Aiming to modernize the exploitation of the gazes of the wasting products from water cleaning system, new owners of "Sofiiska voda" undertake measures for reconstruction of the one gasholder from "wet" to "dry" according to the germen technology. /fig. 1./

The reconstruction project and managing of the construction works have been done by company "Passavant-Roediger", and reconstruction works were done by Bulgarian company. The gasholder has been ready for exploitation in the spring of 2007. In the reconstructed device the water pillow is removed and the moving upper part (bell) is fixed immovable in the maximum raised level. The lower cylindrical part /shell/ of the old gasholder is reinforced with vertical, hot rolled steel columns located on the insider perimeter. The immovable fixing of the upper part (bell) to the lower cylindrical part has been done by stiffening steel ring.

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fig. 1 General view of reconstructed gasholder

According to new technology to ensure variable volume of the stored gas /methane/ it is used a special moving ceiling which moves vertically directed by telescopic column located in centre of the gasholder. /fig. 2/.

fig. 2 Moving ceiling and central telescopic column

There is a flexible rubber membrane between moving ceiling and stiffening steel ring – connecting upper and lower parts of the gasholder. This membrane secures against gas loses going outside. When the moving ceiling has been raised by internal gas pressure, filled in by compressor station, rubber membrane went above the stiffening steel ring and begun to press the supporting grating made by steel rings (galvanized pipes Ø31,8x2,6mm) and supported on them coniferous boards with cross section 35 x100 mm. The supporting grating has been made by 15 steel rings located telescopically on the height at 600 mm distance one from the other and 48 vertically mounted coniferous boards at distance 1220 mm between them. /fig. 3/

fig. 3 General view of supporting grating

3. CONCLUSIONS FROM THE FAILURE INSPECTION

According to the information from the persons in charge with the exploitation the gasholder failure occurred in the night between 1 and 2 of July. Immediately before the failure the gasholder has been filled up to 60 ÷ 70% from the useful volume. The internal pressure of the closed volume has decreased quickly and the moving ceiling collapsed on the bottom of the gasholder with the big thunder. During the inspection made after the failure it became clear that the supporting grating is destructed and rubber membrane is punctured. /fig. 4/

The inspection of the damaged parts permitted to make the following conclusions:

- The supporting grating had the entire translation in the south-east direction and the general displacements are 200 ÷ 600 mm.
- Eight of the steel rings located in the lower part of the grating are torn. Almost all rings are torn on two places positioned in the opposite directions. As a whole the places of tearing coincide with the direction of dislocation.
- All tears of the steel rings (pipes Ø31,8 x 2,6) are in the area of the butt welding joints. /fig. 5/
- Butt welds, connecting the different parts of the rings, have been executed on the site without additional internal rings. The pipes have been delivered hot galvanized on their whole length.
- Considerable part of the vertically positioned boards, located in the area of rings tearing is broken.
- The rubber membrane is punctured on two places and the length of the breaks does not exceed 120 mm.

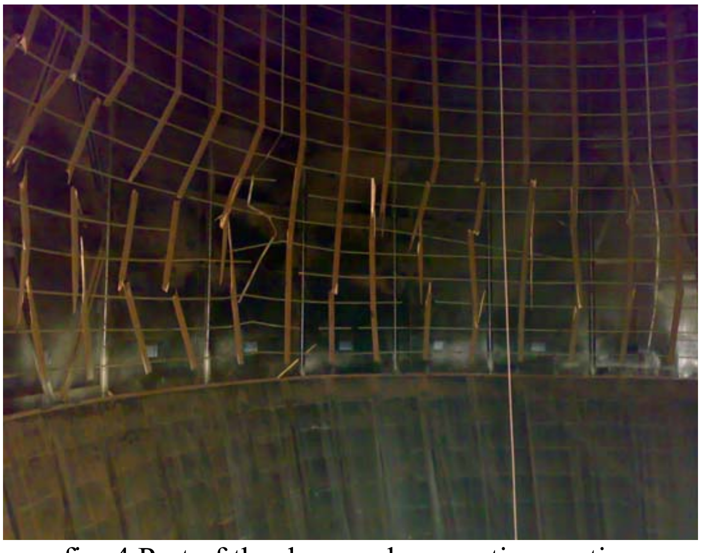

fig. 4 Part of the damaged supporting grating

fig. 5 Broken butt weld of steel ring

The entire inspection of the gasholder after the failure shows the following:

- There is a visible deviation of axe of the telescoping column from the vertical.
- There is clearly visible longitudinal line long more then 3,0 m on the surface of the middle /moving/ part of the telescoping column which is an evidence for high level of friction of roller mechanism located in the basement of the upper part of the telescopic column.
- The ballast, located on the steel ring on moving ceiling, pavement stones, is partially dislocated.
- There is a general deformation of upper part of the shell of gasholder from the theoretical line of vertical cylinder but it is difficult to say whether it is a failure result or it is defect of constructing works.
- There are considerable vibrations in certain roof parts /provoked by jump of somebody/, which is an evidence for not reliable connection between some of the radial roof ribs and the central dome ring.
- Some of tension rods stabilizing the upper part of the telescopic column to the upper supporting ring of the shell are not well tightened.
- There is a visible slump in the roof steel plates and a bulge in the opposite site area.

4. RESULTS FROM THE NUMERICAL MODELING OF SUPPORTING GRATING

In order to obtain enough reliable theoretical data for status of supporting grating when it is under pressure it has been prepared a three dimensioned calculating model with software SAP 2000 /fig. 6/. During the calculating modeling we looked for correspondence with the real construction. For example we accepted for the upper and the lower steel rings pin joints between 15^0 and other intermediate rings are without external supporting but the are connected between them self by the elements with bending stiffness located vertically on the ring at a distance of $7{,}5^0$. Those vertical elements correspond on the soft wood boards in the supporting grating.

The three dimensioned calculating model gives the opportunity to estimate the grating connection between the horizontal steel elements /rings/ and the vertical wooden elements. As a result of the grating connection under the influence of inside gas pressure transferred through rubber membrane they appear in the rings not only tension axe forces /as accepted in the “Passavant-Roediger” project/ but also bending moments.

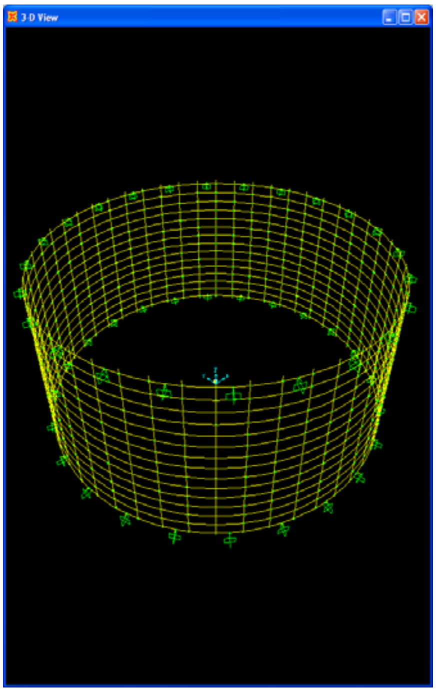

fig. 6 Calculating model

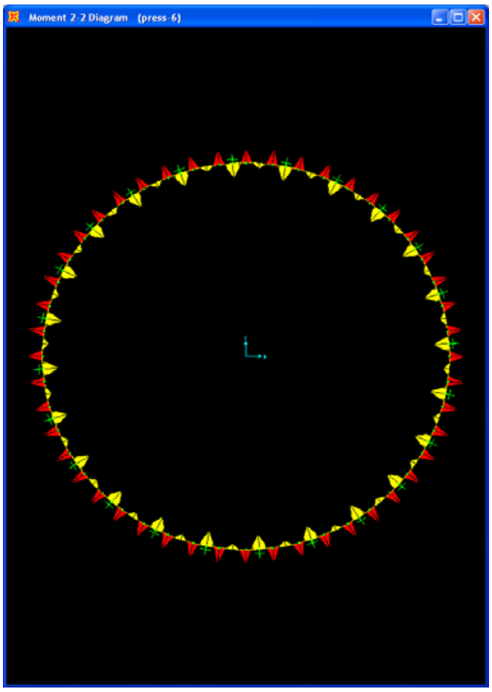

fig. 7 Diagram of the bending moments by the loading of over pressure

During the numerical calculation it has been considered also the temperature impact in compliance with EN 1991 – part 5. It must be considered that the temperature effects caused by climate temperature influence are of considerable importance for not insulated steel construction on the open air as it is in the reported case. There is also an technological temperature impact on the supporting grating caused by the temperature of the stored gas /35^0/. This theoretical research considers also the son radiation effects and uneven dispatching of the temperature.

Temperature deformations and caused by them temperature pressures depends on the geometry and the supporting conditions of the inspected construction as well as on the physical properties of the used materials. The exact determination of the temperature impacts is a difficult task and for the purpose we need true data for air temperature, solar radiation, thermal radiation during the night, etc. In this theoretical research the thermal impacts are considered in the following combinations:

- Warming of the external surface of the gasholder with $+40^0$C and heated supporting grating.
- Irregular warming of determined sector of external surface with angle equal to 90^0, as the additional temperature by the irregular warming is accepted $+15^0$.
- Regular warming of supporting grating with $+35^0$ /exploitation temperature/ as the warming is done consequently first on the first ring, then on the second ring etc.

Some of the results of numerical modeling are shown in the table below:

Пръстен	Нормативни усилия в пръстените от температурни товари, kN и kNm									
	преместване от Δt = 40 ^{0}C		преместв. от Δt = 35 ^{0}C + 15		Δt = 35 ^{0}C - по 2 пръстена		Δt = 35 ^{0}C - по 4 пръстена		Δt = 35 ^{0}C - по 6 пръстена	
	N	M	N	M	N	M	N	M	N	M
8	0	0	0	0	-0,001	0	0,02247	-0,000211	-0,477	0,0052
7	-0,000368	0	-0,000502	0	0,00548	0	-0,07996	0,001072	1,1203	-0,0132
6	0,001636	-0,000225	0,00079	-0,000178	0,0226	0,000169	-0,4771	0,0051	-0,934	-0,0568
5	0,00395	-0,000674	-0,00472	-0,00028	-0,845	0,0012	1,1156	-0,0135	0,2964	-0,0709
4	-0,0211	-0,0019	-0,017	-0,00095	-0,486	0,0044	-0,9428	-0,0558	0,0557	-0,0677
3	-0,15	-0,0065	-0,182	-0,0023	1,205	-0,0168	0,3904	-0,0693	0,0763	-0,0659
2	0,3669	-0,0219	0,446	-0,0273	-0,779	-0,0673	0,2397	-0,0792	0,1629	-0,0784
1 - дъска	4,551	0,0603	5,663	0,0222	-1,732	-0,0745	-2,074	-0,0702	-2,054	-0,0704
1 - опора	4,551	-0,2236	5,643	-0,2775	0,021	-0,0468	-2,124	0,0157	-2,108	0,016

Пръстен	Нормативни усилия в пръстените от свръхналягане, kN и kNm					
	p_0 - по 2 пръстена		p_0 - по 4 пръстена		p_0 - по 6 пръстена	
	N	M	N	M	N	M
8	0	0	-0,029	0,000328	0,174	-0,019
7	0	0	-0,469	0,0052	8,743	-0,0974
6	-0,03	0,00044	0,172	-0,002	17,312	-0,1929
5	-0,469	0,0049	8,744	-0,0971	17,958	-0,2003
4	0,205	-0,0033	17,345	-0,1942	17,545	-0,1944
3	8,735	-0,0941	17,985	-0,2034	17,492	-0,1979
2	16,722	-0,197	16,908	-0,1988	16,876	-0,1985
1 - дъска	16,215	-0,2127	15,796	-0,2072	15,82	-0,2076
1 - опора	16,181	0,2541	15,764	0,2475	15,787	0,2479

Max. нормативни усилия в дъските	
Натоварване	M, kNm
преместв. от Δt = 40 ^{0}C	0,0098
прем. от Δt = 35 ^{0}C + 15	0,0118
Δt = 35 ^{0}C - 2 пръстена	0,0444
Δt = 35 ^{0}C - 4 пръстена	0,0434
Δt = 35 ^{0}C - 6 пръстена	0,0248
p_0 - 2 пръстена	0,1529
p_0 - 4 пръстена	0,1528
p_0 - 6 пръстена	0,1528

5. ANALISYS OF THE RESULTS OF THIS RESEARCH AND MAIN CONCLUSIONS

It is well known that for ascertaining the exact causes /or cause/ for some failure we must analyze very attentively all important facts and circumstances which create such potential threat. Mainly they are:

- Quality of the used materials;
- Strength of executed butt welds;
- Untrue or inexact calculation;
- Bad or unsuccessful detailing of steel structure;
- Bad or inexact mounting works ;
- Incorrect exploitation;
- Over loading under the exceptional circumstances.

The check-up for steel quality of damaged rings shows that its strength and chemical ingredients correspond to the steel mentioned in the project S235. The dimensions of the used pipes correspond to the standard requirements.

The timber used for vertical boards has low strength index and visible defects. The projects did not prescribe type of timber and there are not calculations for wooden elements but our check-up shows that the theoretical tensions of bending under the impact of gas pressure are lower than the strength of the used timber.

An experimental check for the welding joints strength shows that it is 70% from the strength of the main metal of pipes. In the same time, the calculated strength of one butt weld in the steel pipe is bigger then the relevant maximum of the calculated effort mentioned in the project.

The main reason for the relatively low strength of the butt weld joints is technological, referred in the project solution. It is stipulated to butt weld on spot galvanized steel pipes even without a prescription of constructive detail for the execution of this joint. It is well known that zinc galvanization deteriorates the quality of the welding work and makes lower the strength of the welding joint.

During the reconstruction of gasholder and its transformation from “wet” to “dry” several defects have been caused which deteriorate its general condition - the dome’ ribs do not coincide with the vertical columns, welding joints in the central and supporting rings are missing, there is considerable deviation from the cylindrical shape of the grating etc.

Irregular exploitation of the gasholder and its overloading are less probable as a reason for failure because there is a system in device generating pressure, which locks when the pressure is higher.

The comparison of results of numerical modeling of the supporting grating with the calculations of executed project shows the following:

1. Normal tensions in the steel rings calculated through the formula of the “ cauldron” in the realized project are considerably lower than those determined by the three dimensioned calculating model;
2. The accepted cross section of the steel rings /Ø31,8 x 2,6/ is not sufficient for providing their needed bearing capacity;

The analysis of obtained results from the research shows that can not be mentioned a single reason for failure of gasholder‘s supporting grating. There is a totality of unfavorable factors which created conditions for failure itself. Main reasons for the failure are the:

- Not reported additional tensions in steel rings – caused by local bending, temperature impact ect.
- Decreased strength of the mounting butt weld joints connecting different parts of the rings.
- Deviation from the projected position of the telescopic column of supporting grating.
- Insufficient stiffness of fixing of telescopic column to the gasholder roof.

The following main recommendations have been done based on the analysis:

- To prepare project for repairing works of gasholder after an entire analysis of the whole bearing construction;
- To make a review of the project of supporting grating in which the results of current research shall be taken into consideration;
- To build atomized system for control management and analysis of parameters for gas generation /quantity of gas, pressure, level of filling/ by using of indicators in an explosive danger environment.