Two History Cases of Innovations

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ABSTRACT

In late 1970s and through 1980s the Soviet Government and the Communist Party encouraged engineers and scientists to develop innovations, to implement them in order to optimize and to increase the effectiveness of the national economy. “The economy must be economical” was the slogan of this policy. The R@D programs were well funded by the State. The paper describes two failures, linked up with implementation of cost-saving innovations: explosion of a 10,000 m^3 liquid ammonia storage tank, and failure of a raft footing on largely spaced piles.

EXPLOSION OF A LIQUID AMMONIA STORAGE TANK

In 1990 a 10,000 m^3 liquid ammonia storage tank exploded in the town of Ionava in the former Soviet republic of Lithuania. The cylindrical storage tank, constructed and hydrotested in 1978, was completely destroyed, and the ammonia evaporated, and a huge highly toxic cloud appeared. There were fatalities on the facility site. 120,000 residents of Ionava were urgently evacuated away from the cloud. Luckily, there was no wind. The cloud self-ignited and burnt down in several hours without producing additional damage.

The tank was a thermo-insulated steel cylindrical 30.5 m dia tank (Dewar) with spherical top, in which liquid ammonia was stored at 32-34^{o}C. The tank sat above the ground on a two-slab concrete footing with 3.75 m high 0.5x0.5 m concrete columns spanned 1.5x1.5 m between the slabs.

The upper slab of the footing was 35 cm thick: its central portion consisted of 8 cm thick prefab panels with 27 cm cast slab on top of them, the peripheral 35 cm thick and 2.0-2.5 m wide ring was cast concrete. The bottom slab was 40 cm thick. Its depth was 2.25 m. The upper slab was 1.95 m above the ground level.

The space between the slabs prevented thermal contact of the cold tank with the ground. The storage tank was secured to the upper slab by anchors along its periphery. Around the tank there was a 41.5 m dia 14 m high safety wall (Fig.1).

The soil base was dry uniform sand (E=30 MPa). Water table was found at 30 m depth.

The tank was commissioned and hydrodested in 1978. For 11 years of operation, it settled 11-12 cm in the center and 6-7 cm at the edge.

The tank was designed according to innovative cost-effective proposal, which was developed in 1976 by the Project Design Institute of Nitrogen Industry (GIAP), with Gersevanov Research Institute of Foundations and Underground Structures (NIIOSP) scientific support. The conventional prototype had a much heavier footing structure of similar double slab design with the columns rigidly fixed in both slabs. Such design provided for very high overall stiffness of the footing and, respectively, high reinforcement rate.

In the 1970 elastic half-space model of soil base was broadly applied for soil-structure interaction analysis. This model with unrealistic singularities under footing edges overestimated the bending moments in spread footings, because “plastic zones” under footing edges were not taken into account.

After a 3 m Winkler layer was put on top of elastic half-space model, the design bending moments were reduced, a flexible footing option became possible, and the innovative project design was created. The main concept was to arrange sliding joints at the upper ends of the columns. The footing stiffness was reduced manifold, as compared to the prototype.

Since 1978 several ammonia storage tanks of similar design were erected with even thinner slabs. No anomalies were observed.

After the disaster in 1989 the investigation by Lithuanian side concluded that the tank footing was unsafe, because during loading-unloading cycles fatigue of concrete caused failure of the footing, and that the storage tank had high margin of safety while the footing was underdesigned i.e., too flexible.

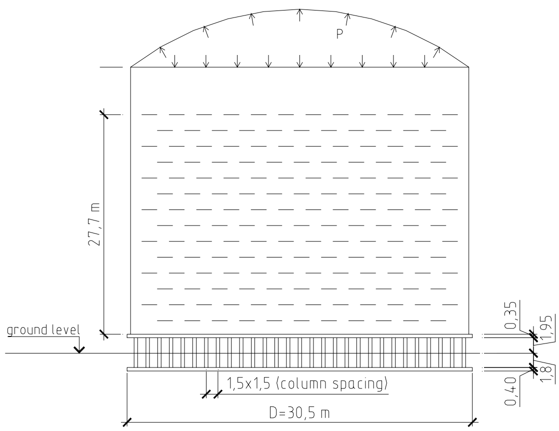

Fig. 1. Cross section of the liquid ammonia storage tank in Ionava, Lithuania

GIAP applied to NIIOSP to give the objective judgement. Therefore, an extensive numerical simulation was carried out. The numerical results showed that edges of the upper slab "curled up" and broke, because the peripheral anchors and the tank itself featured excessively high strength. The same "curle-up" failure was observed on site. Hence, tank tended to become a sphere just like an air balloon. The right conclusion was that due to increase of temperature liquid ammonia started boiling and gaseous phase formed up above its surface. The pressure from the inside of the tank raised much higher than that of the ambient air. Although due to its large dimensions the steel tank was very flexible, but it could not become a sphere, because it was held in place by peripheral anchors, therefore, its side broke, and the tank was jettisoned in the direction opposite to the broken side.

The real cause of the disaster has not been not published so far. GIAP and NIIOSP were never involved in any forensic enquiry.

CREEP PILES

In USSR before 1980s piles were conventionally spaced at 3d (d being pile diameter) if predicted settlements exceeded the allowable values of the Construction Code. But often pile raft settlements were much less than the allowable values i.e., piles could have been spaced farther than 3d. But then the piles and the raft had to be redesigned to bear greater loads. A trade-off had to be found, but simple calculations showed that a thicker raft on thicker piles, bearing greater bending moments and shear forces, was often more cost-effective than closely spaced piles of smaller diameter, especially if the raft transmitted a portion of load to the soil surface.

The practice of largely spaced "creep" piles, which are loaded to their ultimate bearing capacity was published in (Goncalves H.H.S., 2005). Also a 16-storey building was erected on largely spaced piles in London (Great Britain), where the number of piles was reduced ninefold.

This concept of larger pile spacing was implemented in 1980s in Sukhumi, capital city of Abkhazia (then an autonomy of the Russian Soviet Federative Socialist Republic) by the local general contractor, Abkhazstroy (Arshba E.T., 1989), with NIIOSP technical advice. Several residential buildings were constructed on largely spanned piling and have been in service ever since. These buildings did not tilt, and this was their great advantage. Sukhumi is located in a coastland zone by the Black Sea and has highly heterogeneous soils of various types. There are many tilting buildings in Abkhazia, including the head office building of the above general contractor.

The situation in Abkhazia is very similar to that in the city of Santos in Brazil, which is also situated in the coastland zone by the Atlantic ocean (Goncalves H.H.S., 2005).

In 1986 a residential building was erected in Sukhumi, capital town of Abkhazia (Frederiksson A., Rosen R., 1983). The building consisted of two separate 9-storey sectors with an insert between them, connecting the two sections by passages on each floor. The two sectors and the insert sat on one 40 cm thick concrete slab, which was supported by 12 m long driven 35x35 cm piles spaced at 3x3 m (Fig. 2). Conventionally pile spacing was 1x1 m, but it was often impossible to drive so closely spaced piles to the design depth. The 3x3 m spacing reduced the number of piles almost ninefold and facilitated pile driving operations.

Also it was proved later that concrete quality in the raft of one of the sectors was lower than designed. After the building was completed, the piles "punched through" the raft of one of the sectors. The raft of the other section had sufficient strength to bear the load. This failure was also due to the fact that the upper soil was soft (5-7 MPa), and it was underlain stiff gravely soil (30 MPa), therefore, the piles were point bearing i.e., practically no load was transferred to the soil between the piles.

The settlements of the two sections are shown on Fig. 2

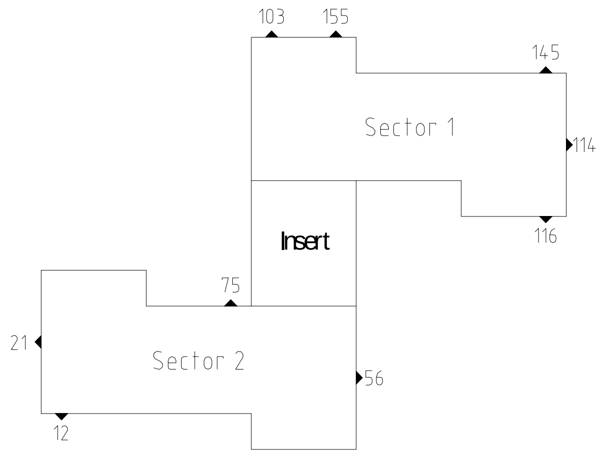

Fig. 2. The raft overview, showing measured settlements (mm)

The failed raft sector had greater settlements and tilted more than the other one. To stop further settlements the basement of the failed sector was filled with concrete mixture.

There is no further information, because Abkhazia entered the period "perestroika" and later war started between Abkhazia and Georgia.

This history case gives realistic evidence of largely spaced piling advantages and possible risks.

Later, combined pile raft footings (CPRF) became very popular in Russia and internationally. Russian Construction Code SP 50-102-2003 has recommendations for the CPRF analysis, design and erection.

Many tall buildings in Germany were designed and erected on largely spaced piles under the guidance of Prof. Rolf Katzenbach of Darmstadt University (Katzenbach R., 2006).

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