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THE CASE OF THE VIBRATING SUPERFRACTIONATOR

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ABSTRACT

A tall fractionator tower, part of a super fractionation unit in an aromatics plant of a petroleum refinery, was originally built by a very reputable pressure vessel fabricator with extensive experience.

The fractionator used in the production of Xylene performed well for a number of years without any difficulties. Then, suddenly, when a drop in price of aromatics led to a shutdown of the unit, the empty tower started to vibrate violently at moderate wind velocities. As soon as the tower was filled with liquid, the vibrations stopped; however, over a period of 10 years with on and off vibrations, the anchor bolts were apparently stretched beyond the yield point of the material. An investigation into the strength of the foundation also showed insufficient safety against overturning.

This paper describes the accumulated damage done to both, tower and foundation, also the very expensive repair work required to make the tower structurally sound. The repair took almost one year to completion, partly due to the fact that work had to be done while the refinery was on-stream.

The repair, of course, did not fully eliminate the reasons for the vibrations. An automatic system had to be devised to sense vibrations during periods of shutdown of the process unit, and automatically initiate a sequence to fill the tower with liquid whenever excessive vibrations are detected.

INTRODUCTION

This paper reports about a refinery fractionator tower which, when purchased, was only a small part of a process unit. When excessive vibrations questioned the integrity of the tower, including the foundation, no easy repair or replacement was available. Out of several alternatives to remedy the situation, the one chosen was one which permitted the use of the facility where the fractionator is installed during the course of the repair work. It requires, however, extensive monitoring during its future lifetime.

The fractionator in question was installed about 25 years ago, when the owners of a petroleum refinery decided to add a plant producing aromatics as feed stock for the plastic industry. Among the products to be produced was Xylene, which required a very tall fractionator, 3.6 m in diameter and 70 m high. At that time, this tower was much taller than any other structure, not only in this refinery, but generally in the petro-chemical industry. Not much was known in this industry about wind induced vibrations at moderate wind velocities. Towers and fractionators were designed using a static wind force based on the maximum wind velocity for a given locality.

Due to the fact that there was little space available for location of the aromatics unit, it was decided to place the order for this fractionator with a well known company, very experienced in the fabrication and erection of process equipment, for on-site construction.

At about this time, based on structural failure of cooling towers and other equipment susceptible to "Vortex Shedding Vibrations", the Building Code of Canada [1] [2] published the first non-mandatory rules for the investigation and adequacy of tall structures subjected to such kind of vibrations. The company which constructed the fractionator was advised of the danger of wind induced vibrations but decided against the use of new, unproven design methods and stuck to their know-how based on many years experience. Unfortunately, nothing in their experience had prepared them for the peculiarities of very tall towers.

The tower design was based on a static wind load, reduced for the proximity of other nearby towers which, of course, were not as high as the fractionator in question. The design was registered with local authorities who accepted the fabricator's design calculations on the basis of the reputation of this company. When questioned by engineers of the owner company about wind induced vibrations, a review was made and guy wires were added during construction only. The owner was assured that, once the tower was fully erected, there was no danger of wind vibrations.

The tower and other equipment of the aromatics unit were commissioned and accepted, feed was put into the unit and, after some initial glitches, the unit performed well. No wind vibration problems occurred. The fractionator performed well without difficulties for several years.

When, during an economical downturn, the price for aromatics dropped considerably and it was decided to shut the unit down, the first problems started. During a period of steadily blowing wind with moderate velocity, the empty fractionator started to vibrate violently. As soon as a feed circulation was re-established and the tower trays were filled with liquid, the vibrations stopped. An analysis showed that the calculated natural frequency of the tower in an empty condition was in resonance with the vortex shedding frequency at moderate wind velocities. The natural frequency of the tower in operating condition, however, did not cause resonance, hence no vibrations were observed when the tower was operating.

The tower was operated for 10 years after the first vibrations were observed. An operating procedure was established to quickly fill the tower during a shutdown, whenever vibrations were observed. This seemed to be a stop-gap measure, but since the refinery changed ownership, nobody of authority wanted to commit major monetary expenses to remedy the situation.

During a period of several cases of very strong vibrations, it was also observed that the tower base was no longer rigidly connected to the foundation. When an incident of vibrations coincided with heavy rain, water could be seen being squeezed out under the tower base ring. This occurrence initiated a series of tests to find out if the structural integrity of the tower plus foundation had been compromised.

After the fireproofing concrete had been removed it was found that almost all 24 anchor bolts of 64 mm diameter (2-3/4 inch) were loose, in spite of double nuts originally installed. This proved that the anchor bolts had been stressed beyond the yield point. Also, dynamometer measurements were undertaken to find the exact natural frequency of the tower in both the empty state and the operating condition. Both frequencies were very close to frequencies calculated using a simplified method of analysis [3].

A design verification of the foundation showed that the factor of safety against overturning was a mere 1.15 instead of 1.5 as required by the building code. Also, the stresses in the support skirt greatly exceeded the allowable stresses of the material.

As a stop-gap measure, the anchor bolts were tightened and the tower was kept filled with liquid for as much time as was possible, from an operating point of view.

REPAIR OPTIONS

When it was discovered that the anchor bolts had stretched, it became obvious that something had to be done to ensure the integrity of the fractionator and also the whole process unit where it was located. A number of possibilities were discussed and discarded; eventually, the choice was brought down to the three following options:

(a) To replace the tower on a new foundation
(b) To decommission the unit and dismantle the tower.
(c) To strengthen support skirt and foundation

Option (a) was thought to be the preferable one. However, a detailed design study showed that an adequately sized octagonal foundation would interfere with other equipment foundations already in place. Also, the dismantling of the existing fractionator, and the erection of a new one, in the middle of process units on stream, was thought to be too much of an interruption of the refinery processes.

Option (b) was favoured for a while, but as the demand for plastic feed stocks increased, this option was also discarded in order to remain competitive.

This left only option (c), by elimination. A strengthening of support skirt and foundation, of course, would not completely eliminate vibrations. It would, however, provide a safe foundation of adequate safety against overturning, and also a tower support skirt stressed within allowable values.

When the go-ahead for the engineering work of the repair was given, it was understood that an automatic motion detection system and initiation of a tower filling sequence was also required as part of the repair.

After going through some studies and evaluations, a configuration with a new, tapered support skirt was chosen - a skirt which could be installed outside the existing vessel, as shown in Figure 1.

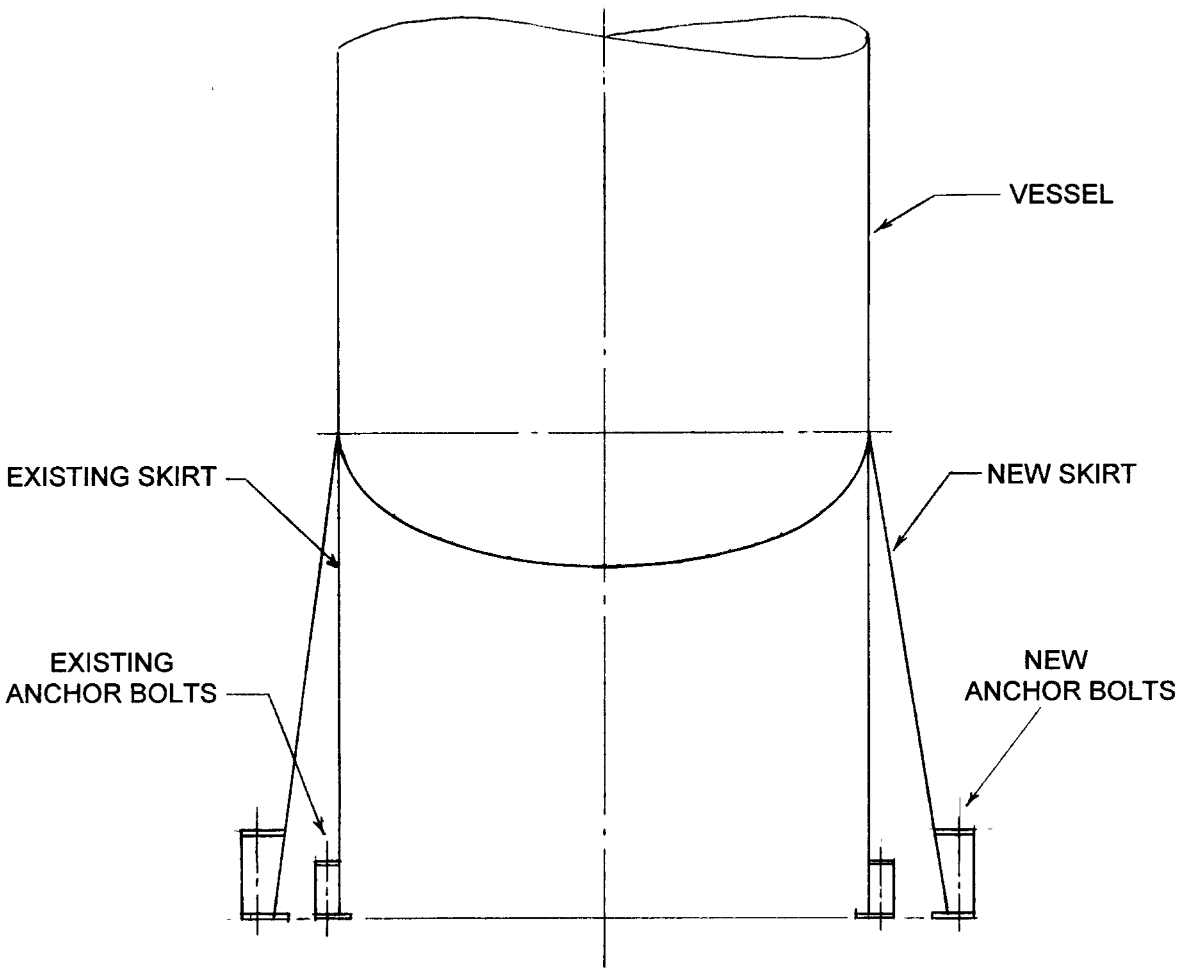

Fig. 1, New Support Skirt Arrangement

FOUNDATION REPAIR

To provide more mass for the foundation to improve the factor of safety against overturning proved more difficult than was thought. An initial configuration with an enlarged octagonal base was found to be impractical because of the proximity of another fractionator foundation. It would have required a common foundation of enormous proportions and the dismantling of other equipment, such as pumps and heat exchangers.

A lucky circumstance aided in finding a reasonable solution for the foundation repair. The original foundation was built on a bed of crushed stone spread over a bed of layered lime stone, only 300 mm below the bottom of the base slab. Test borings conducted around the tower foundation showed that solid rock was only 1.2 to 1.5 m below the top of the rock stratum. Thus it was decided that rock anchors should be used and connected to the new anchor bolts of the tower. This arrangement is shown in Figure 2.

36 holes for the rock anchors were drilled outside the tower pedestal, through the existing octagonal foundation, through the layered lime stone shale and a minimum of 1.5 m into the solid rock formation. Then 36 rock anchors of 50.8 mm (2") diameter were inserted in the drilled holes and adhesively bonded to the rock. The top of the anchors was cut about 300 mm (12") above the foundation and couplings were installed on the anchors.

NEW SUPPORT SKIRT

A new tapered support skirt was designed which could be installed around the existing vessel and welded in place. The arrangement of the new skirt is shown in Figure 3. The new skirt was fabricated in two halves and shop fitted before installation around the existing support skirt. There was some misfit between the new skirt and the existing vessel shell due to a small out-of-roundness on the vessel. The misfit, however, did not exceed 3 mm (1/8") and could therefore be accommodated in the skirt-to-shell weld. The existing skirt and anchor bolts were left in place.

VIBRATION MONITORING

After installation of the new support skirt and the new anchor bolts imbedded in rock, the tower vibrated again when empty during a period of steadily blowing wind. The new skirt and anchor bolts had, of course, not eliminated the basic fault of the fractionator: resonance with vortex shedding vibrations.

It was then decided to install a vibration monitoring dynamometer which, when a certain amplitude is exceeded, will initiate a tower filling sequence. This sequence, as conceived, is fully automatic such that tower vibrations can be stopped before they become too violent.

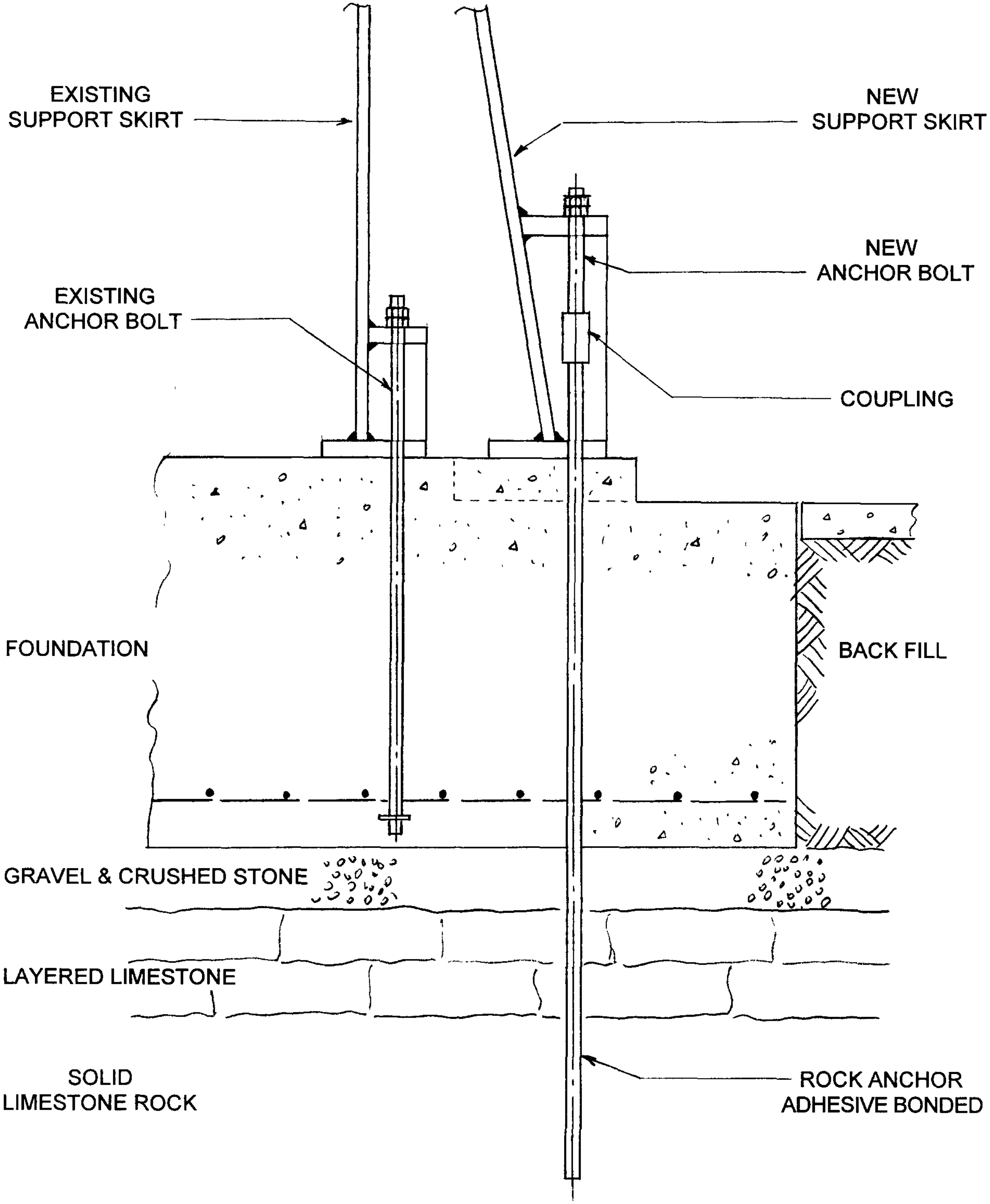

Fig. 2, Rock Anchor Installation

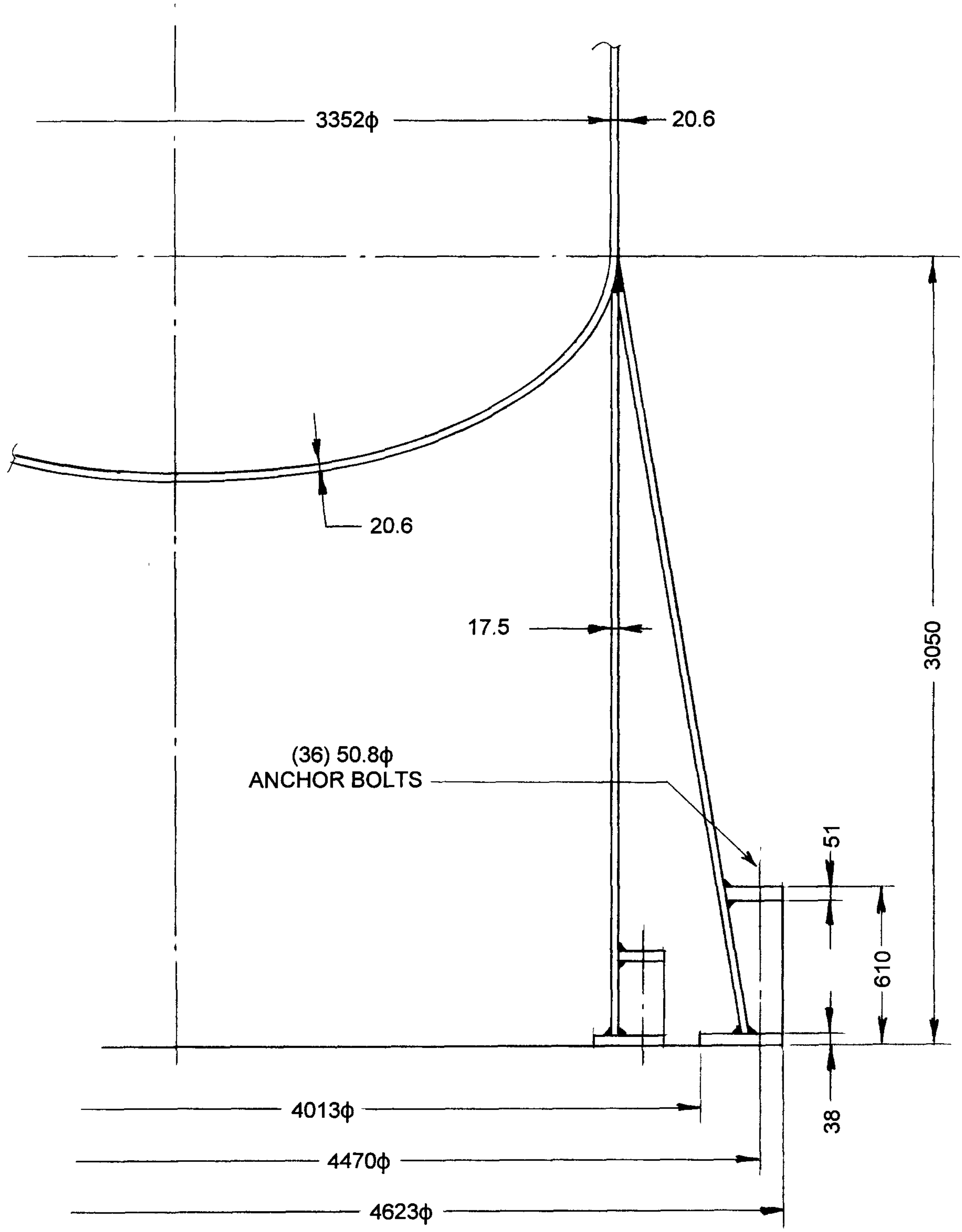

Fig. 3, New Support Skirt

CONCLUSIONS

The high costs of repair of the vibrating Xylene fractionator showed clearly that it is better to invest in a higher initial cost when purchasing process equipment than to obtain the lowest price, including problems which are often associated with it. In the case described a design taking into account possible wind induced vibrations would have required heavier wall thicknesses, thus resulting in higher initial costs whwn purchasing the tower. But in retrospect, it definitely would have been worth the extra cost.

REFERENCES

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[3] A.E. Blach: "Natural Frequencies of Vertical Process Vessels using the Personal Computer", Proceedings, 9th International Modal Analysis Conference (SEM), April 1991, Firenze, Italy, pp 1328-1334.