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Vibration Analysis on a Cement Mill Foundation

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ABSTRACT

In the present case study, the causes of the high vibrations on a double-drive cement mill is investigated by performing a series of vibration measurements on the cement mill pinion and the main bearings, and on the concrete foundation with a multichannel vibration analyzer. FFT (Fast Fourier Transform) and ODS (Operational Deflection Shapes) measurements were made to find out the dominant frequencies of vibration energy and the behaviour of the concrete structure at this particular frequency. Through the use of the "Operational Deflection Shapes" technique together with FFT analysis the main source of the vibration generation mechanism was identified. In the ODS method, the vibrations of the selected points on the structure in the measured direction are recorded with respect to a reference signal. This information is then processed to simulate the vibration of the structure in the measured direction. In the present case 10 points on the foundation were selected and the vertical vibrations of the foundation were measured. As a consequence, the source of the vibrations on the mill was identified as the asymmetry and the weakness of the foundation structure.

1 INTRODUCTION

The method of "Operational Deflection Shapes" (ODS) is a technique where one can simulate the vibration behavior of the structure under operating conditions by measuring the response signals. ODS is a combination of the forcing function acting on the structure and the dynamic properties of the structure. In contrast to Finite Element Method and Experimental Modal Analysis, ODS gives no information about the inherent dynamic properties of the structure such as modal frequency, mode shapes and modal damping. Still, the ODS of a vibrating structure can provide very useful information to aid in the understanding of the dynamic behaviour of the machine under dominant operational forcing frequencies.

Using this method, motion of the selected points on the structure in the measured direction with respect to a reference point are recorded. In spectral ODS technique, phase assigned spectrum is measured at each point which includes the vibration and phase information at each frequency. This information is then processed to simulate the vibration of the structure in the measured direction at a particular operation frequency.

In the present case, 10 points on the foundation are selected and the vertical vibrations of the foundation are measured. Normally, for a rigid concrete structure, one expects to have a rigid body motion. However, in this case study, it is seen that this is not the case for the drive side of the foundation.

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Vibration measurements are taken on the cement mill pinion bearings and on the concrete foundation. ODS (Operational Deflection Shapes) method is used to determine the motion of the concrete structure at different frequencies. Additionally, bearing vibrations are measured and FFT (Fast Fourier Transform) analysis is used to find out the dominant frequencies of vibration energy. Brüel & Kjær PULSE multichannel analyzer, Type 4370 accelerometer, Type 2635 charge amplifier and ODS software is used for measurements and analysis.

Figure 1 shows the schematic drawing of the cement mill system. The frequencies of the system components are as follows:

Girth Gear Speed	: 15,7 RPM = 0,261 Hz
Pinion Speed	: 110 RPM = 1,84 Hz
Toothmesh Frequency	: 49,5 Hz

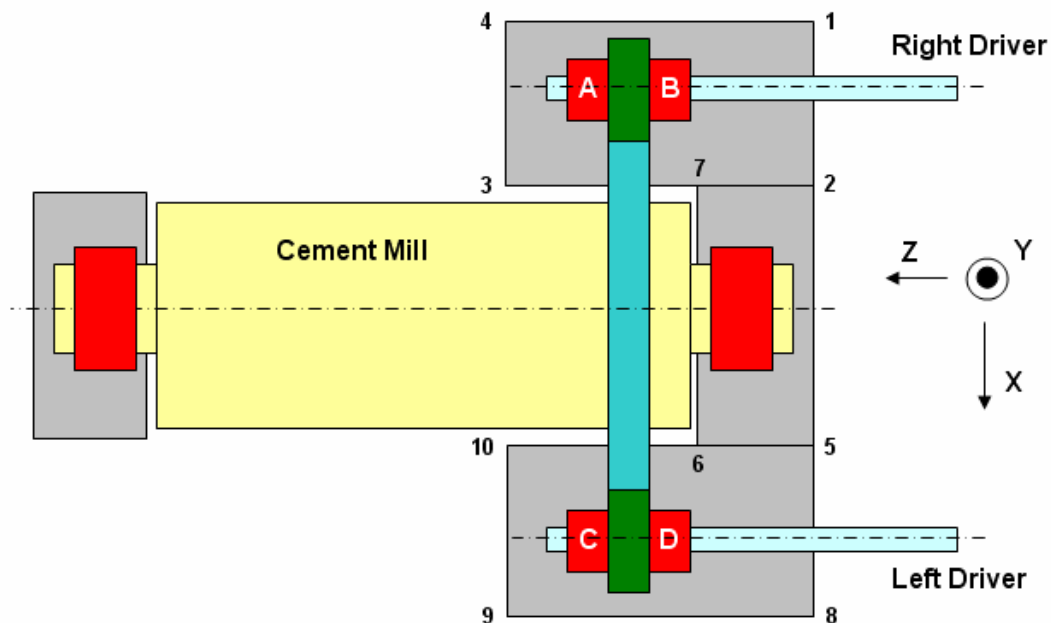


Figure 1: Schematic drawing of the cement mill system.

2 ODS – VIBRATION BEHAVIOUR OF THE FOUNDATION

Figure 2 shows the deflection of the concrete structure upper frame surface. It is seen that the concrete structure of the right driver side is vibrating at 49,5 Hz which is the toothmesh frequency of the Girth-Pinion couple.

Looking at the mill bearing foundation drawings (see Figure 8), it can be clearly seen that the right driver side is much weaker than the left one. The foundation has a weak cross section which may allow bending about an axis parallel to the mill rotational axis. Due to this asymmetry the block under the right side pinion undergoes an elastic deformation and moves like a wing. Hence, the foundation block does not move as a rigid body. The vertical vibration of the frame points 1 & 4 are out of phase compared to the opposite points 2 & 3. This shows that the frame has torsional vibration about an axis parallel to the rotation axis of the mill. The figures below show that the right side vibration deflections are much greater than the left side.

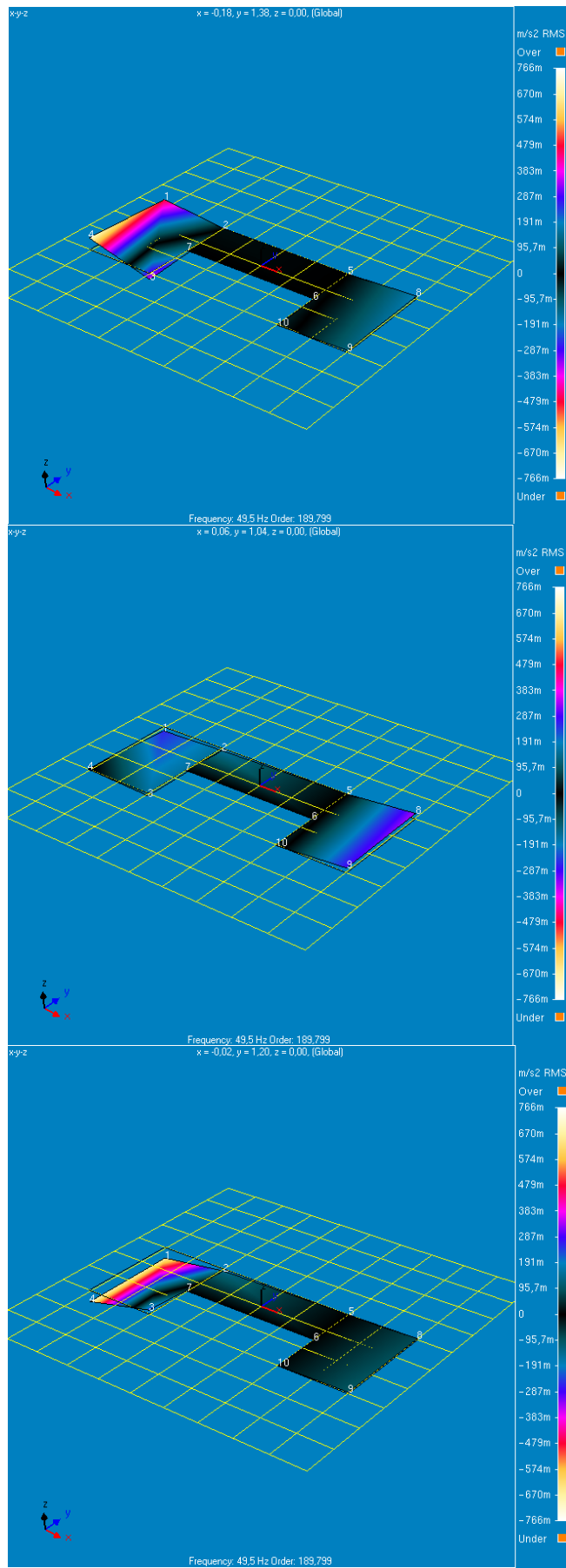


Figure 2: Deflection of the concrete structure upper frame surface at a frequency of 49,5 Hz.

3 VIBRATION TIME PROFILE ON THE FOUNDATION

Figures 3 & 4 show the vibration time profile measured on the right side driver foundation. The vibration on the foundation reflects the vibration of the gear toothmesh. On Figure 3, it can be seen that there is an amplitude modulation at a period of approx. 4 seconds that corresponds to a single revolution of the mill. Figure 4 shows the toothmesh vibration of the Girth-Pinion gear couple. Every 20 milliseconds, there are two peaks instead of one. This behaviour is a symptom of the disorder in the gear operation.

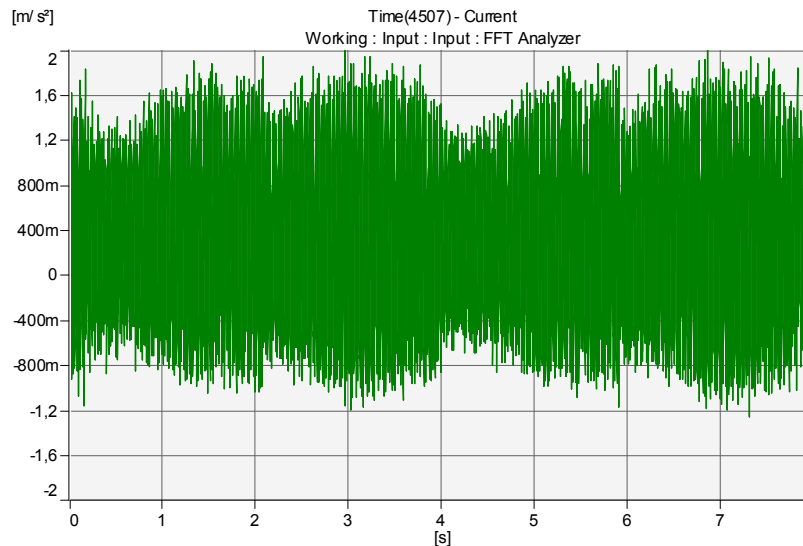


Figure 3: Vibration time profile (Point 1 - Vertical).

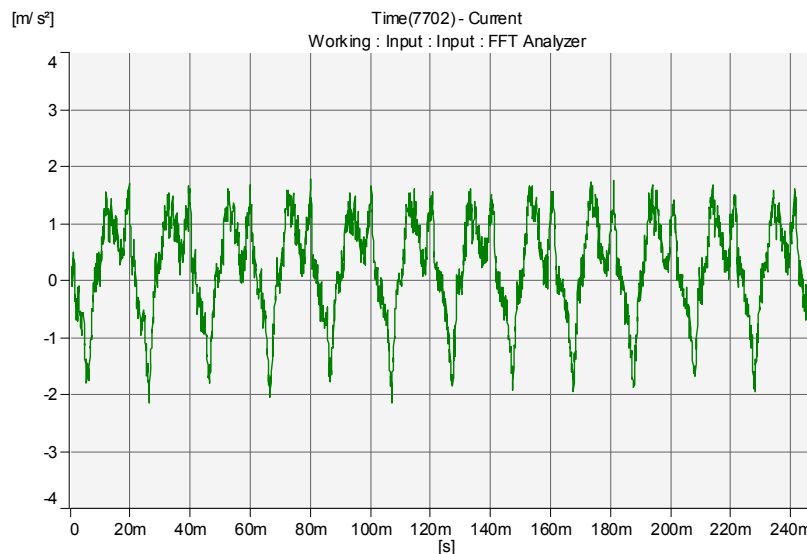


Figure 4: Vibration time profile - zoomed (Point 1 - Vertical).

4 PINION BEARING VIBRATIONS

Table 1 shows the measured overall vibration levels on pinion bearings at 3 directions.

Table 1: Bearing vibration levels (mm/s RMS).

	Brg. A	Brg. B	Brg. C	Brg. D
X	13.9	10.3	7.43	3.80
Y	3.27	3.47	2.52	2.60
Z	7.16	3.31	8.19	2.20

The highest vibration is on the A and B bearings in X direction. Figure 5 shows the frequency spectrum of these two bearings.

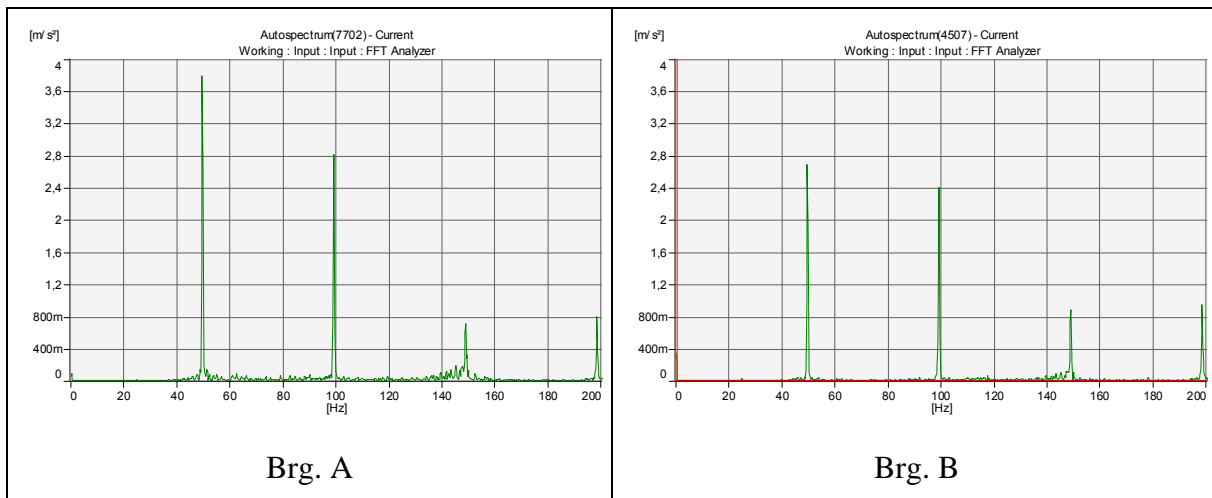


Figure 5: Brg. A & B horizontal vibration spectra.

The above two FFT graphs on Figure 5 show that the vibration on the bearing consists of the gear mesh frequency of the Girth-Pinion couple (49,5 Hz) and its harmonics (99 Hz, 148,5 Hz, etc.).

As there is no peak at the pinion revolution frequency 1,84 Hz and its second harmonics, we can say that the vibration is not effected by the slightly bent pinion driver shaft. The magnitude of the modulation frequencies in the neighbourhood of the toothmesh frequency are very low, showing that there is no wear or crack on the teeth of the gears.

$f_g = \text{No of gear teeth} \times (\text{rpm}/60) \times n$, where $n=1,2,3,\dots$ is called the gear mesh frequency and its harmonics.

It is clear that the gear mesh frequency of the Girth-Pinion couple (49,5 Hz) and its harmonics (99 Hz, 148,5 Hz, etc.) are the main source of the vibration.

The cause of this type of vibration is usually,

- Eccentric pitch circle
- Tooth errors in gear
- Poor gear mesh

Poor meshing, wear of meshing surfaces, uneven wear of meshing gears, resonance of the gear train can be the main sources of vibration. If there are harmonics in the signature the cause could be due to skewed axes of rotation.

5 CEMENT MILL BEARING VIBRATIONS

Horizontal vibration measurements taken from the bearings of the cement mill are shown below (Figure 6). The Graph on the left stands for the drive-end bearing vibration and the right graph for the non-drive-end. It can clearly be seen that the vibration amplitude on the non-drive-end is higher than the drive-end, at the toothmesh frequency of 49,5 Hz. This shows that the gear meshing vibrations are transmitted to the non-drive side via the mill structure. The phase difference between the two measurement points at 49,5 Hz is 182°.

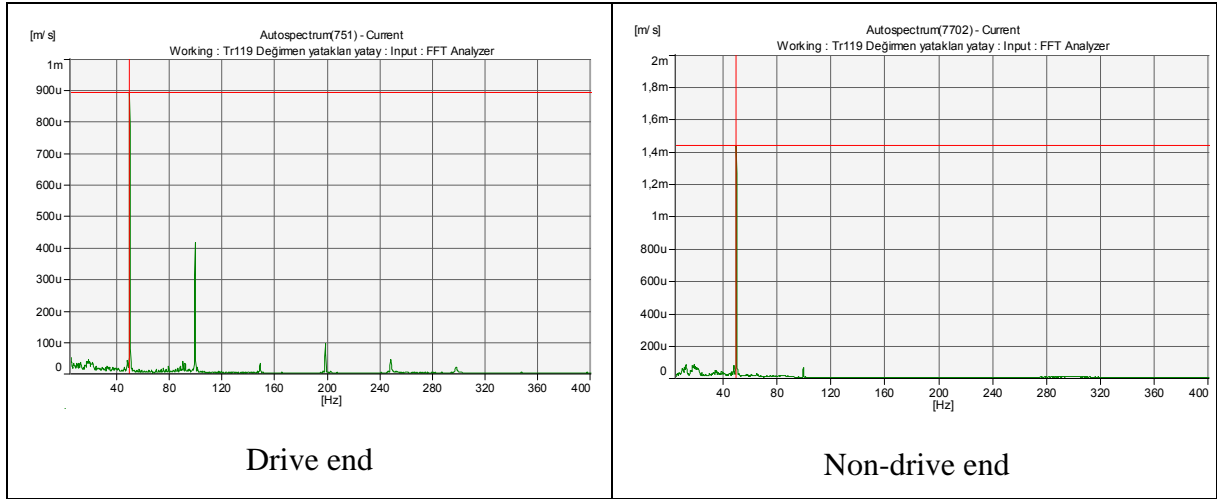


Figure 6: Mill bearing horizontal vibrations (Phase difference at 49,5 Hz = 182°).

6 RIGHT DRIVER PINION CONCRETE FOUNDATION VIBRATIONS

Before our measurements, a concrete reinforcement work was conducted on the top part of the foundation under the right driver pinion. Two accelerometers are used to identify the vibration behaviour of the concrete foundation of the right driver pinion (Figure 7). One accelerometer is placed on the wall of the new concrete section at the bottom in the vertical direction (left graph). Other accelerometer is placed on the top of the concrete structure in the same vertical direction. The phase measurements indicate that there is a phase difference of 157° between the old and newly reinforced part of the foundation.

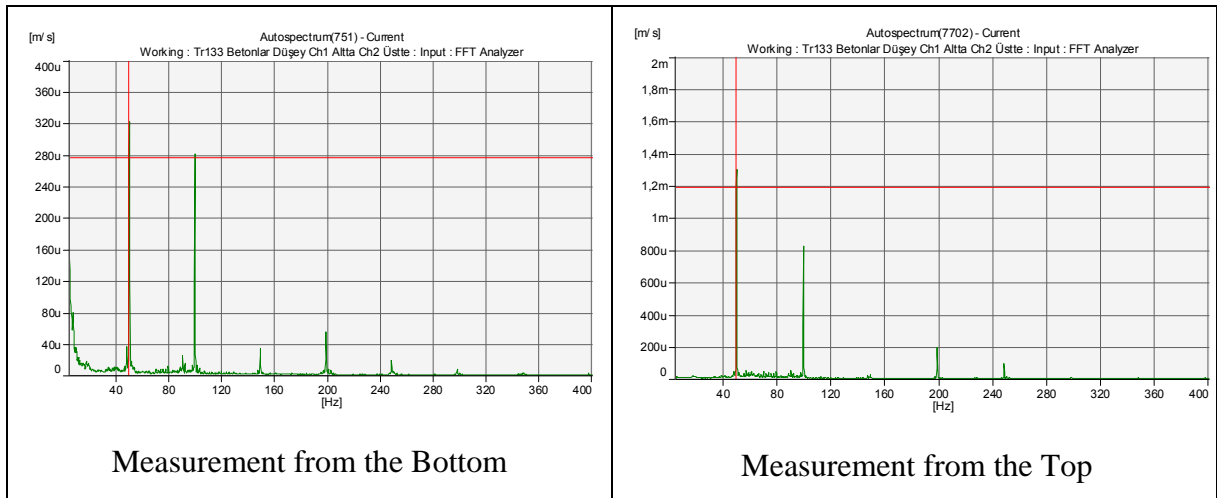


Figure 7: Right driver pinion concrete foundation vertical vibrations. (Old and new blocks phase difference at 49,5 Hz = 157°).

7 CONCLUSIONS

7.1 Findings

The high vibrations on the right side driver pinion bearings are at the toothmesh frequency of the Girth-Pinion gear couple. The vibration forces created on the gears are being transmitted to the concrete foundation. As the foundation is weak, the gearmesh forces cause the foundation to deform and vibrate at that frequency. The ODS animation shows that the right driver side foundation has a torsional vibration about an axis parallel to the rotation axis

of the mill. This causes a relative motion between the gears. And the gears operate in disorder and result in the skewness of the pinion axis with respect to Girth gear rotational axis.

In our opinion the coupled bending and torsional type of vibration of the right side foundation produces the skew in the axes of rotation of the pinion which subsequently triggers the harmonics.

Apparently the new concrete block built under the right driver pinion foundation during the first few days worked well then a separation occurred. This is clearly demonstrated by the simultaneous vertical measurements made on the old upper block and lower reinforcement block. If both blocks are moving together then the phase angle should be zero, however, there is a phase difference of 157° between the old and newly reinforced part of the foundation indicating that these blocks are almost moving against each other.

Vibration and phase measurements made in the horizontal plane on the mill bearings at the drive and non-drive side indicate a phase difference of 182° and considerable vibration on the non-drive side in the horizontal plane. This implies that the mill is doing a yawing with respect to the vertical Y-axis.

All the measurements indicate that the foundation system is weak both against the vertical and horizontal movements especially on the right side at the drive end.

7.2 Recommendations to Solve the Problem

Reinforcement should be made on the right driver side of the foundation to avoid excessive bending and torsion and check to see if there is any skewness in the axes of rotation of the mill axis and the pinion axis on both sides.

Filling the bottom cavity of the right driver side foundation and making it stiff enough will help to overcome the forces generated by the toothmesh. If possible, reinforcing the left side foundation should also be considered. The foundation must be strengthened with proper steel supports from inner side, so that the concrete block will be prevented from coupled bending and torsional vibrations (see Figure 8).

Also the non-drive end foundation should be connected to the drive end foundation with stiff steel supports, so that the whole system will behave as a single foundation.

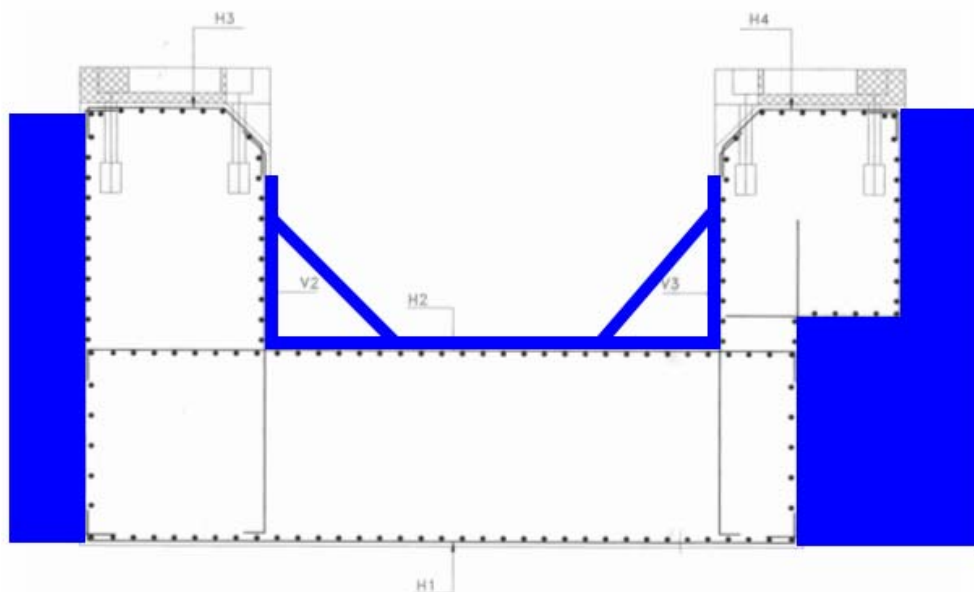


Figure 8: Concrete structure reinforcement recommendations (in blue).

8 REFERENCES

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