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The Demolition of Silos in Genoa, Italy

An Example of Synergy

By Danilo Coppe, Andrea Reggiani, Adolfo Bacci, and Amanda M. Vernò



Introduction

This article describes the demolition of the Genoa grain silos – a project that served as an example of a new generation of demolitions where different technologies, often in competition, come together to obtain the optimal solution to a problem. Dynamite, diamond wire, and hydraulic excavators overcame the most impressive building in town, working in very small spaces and on a geotechnically difficult site. Moreover, a study on the dynamics and the effects of the impact of the structure, an analysis of the presence of potentially explosive dusts, and an extensive vibrometric monitoring, supported the design and development of the operations.



With its massive volume of 160,000 cubic meters (more than 5.6 million cubic feet), standing on a pier of the old Genoa harbor and exactly in the middle of its historical center, Genoa's grain silos, built in the sixties, represented the biggest obstacle to the ongoing harbor renovation. The harbor renovation will include plans for a new urban square, a museum dedicated to the sea and navigation, and new buildings for the local university. But before this new construction could take place, a number of problems connected with the demolition of the existing structure had to be overcome, in particular:

- the small space around the silos could restrict the ability to operate with machines of adequate dimensions;
- the volume and height (up to 76 meters, 250 feet) of the structure itself;
- the need to protect a couple of adjacent buildings already under refurbishment;
- the low mechanical strength of the pier, built between 1883 and 1886;
- the potential presence of explosive dust inside the silos' chambers; and
- the necessity of the lowest possible interference with the daily harbor's activities.

The Design

Due to its originality, the project produced several perplexities in the beginning as it included a segmentation of the structure in ten independent "slices" through several diamond wire cuts, and the subsequent demolition of each of those by the use of explosives in order to reduce the global impact on the pier and vibrations on the nearby buildings. The phasing of the demolition would facilitate the removal of debris avoiding covering the whole pier and excluding the fall of rubble of any kind into the sea.

Since the wharf would have absorbed the energy from the demolition of each slice integrally, a geological survey had to be conducted in order to investigate the relevant characteristics of its structure, foundations and supporting soil. The result was a very low mechanical strength. This fact led to a study through mathematical models in order to evaluate the risks connected to the demolition, the damages that could have been possibly made and an investigation of the procedures and countermeasures needed to minimize the effect of the smash

of each slice of the silos on the ground in order to allow the pier to tolerate all the ten impacts.

Dynamic Analysis of the Impact of the Structure on the Pier

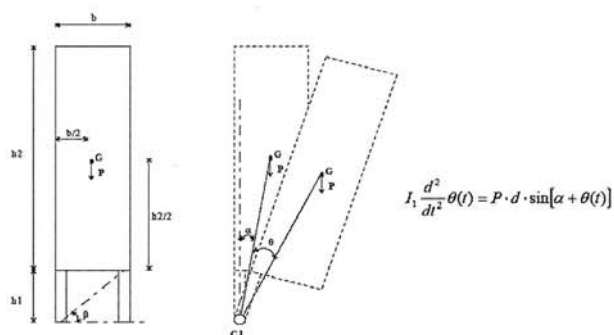
Each of the slices was designed to leave after the cut, two rows of four pillars each. After eliminating the front row through internal explosives charges, the structure would surely knock over onto the wharf.

As it was clear that the pier could not withstand the impact without protection, a sort of "cushion" had to be designed and built on it before each explosion to protect it from the mass of the falling silos while absorbing and dissipating part of the energy without transmitting it to the ground below. The challenge was to find an accurate way to design this protection both in terms of size and positioning.

The best way to do this was a FEM (finite elements method) analysis of the wharf to investigate its deformations and reactions when subjected to the impact of the falling mass of the silos.

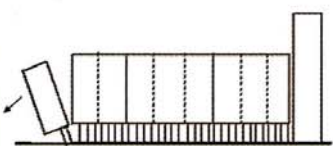
Therefore another extensive investigation had to be done to characterize in detail the mechanical and physical properties of the material constituting the wharf (weight, Young's modulus, Poisson coefficient, etc.), and those of the protective gravel cushion whose reaction to the impact was then set equal to its resistance to compression. To determine the forces acting during the fall and the impact, the silos' motion was modeled in three separate phases and an equivalent number of equations were used to describe the motion as follows:

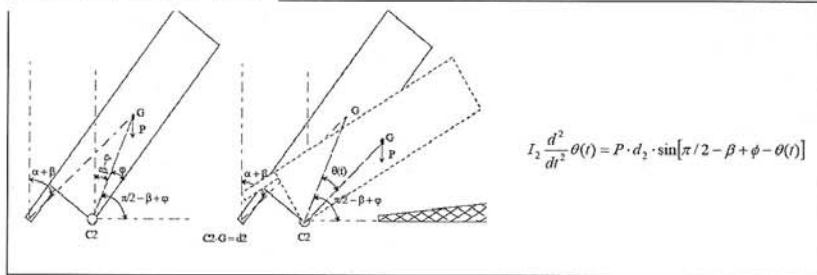
- **Phase One** starts just after the detonation and ends with the contact of the lower part of the silos on ground, center of rotation is the base of the remaining pillars, where: $0 \leq \theta(t) \leq \beta$



Phase One Motion Model.

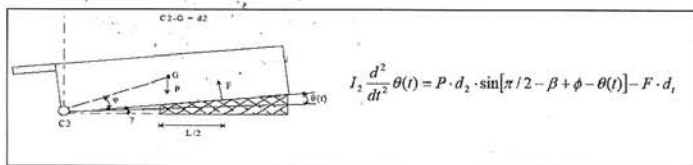
- **Phase Two** starts at the contact of the lower part of the silos on the ground and ends with the impact on the gravel cushion, center of rotation is the lower edge of the structure, where $0 \leq \theta(t) \leq \pi/2 - \beta - \gamma$





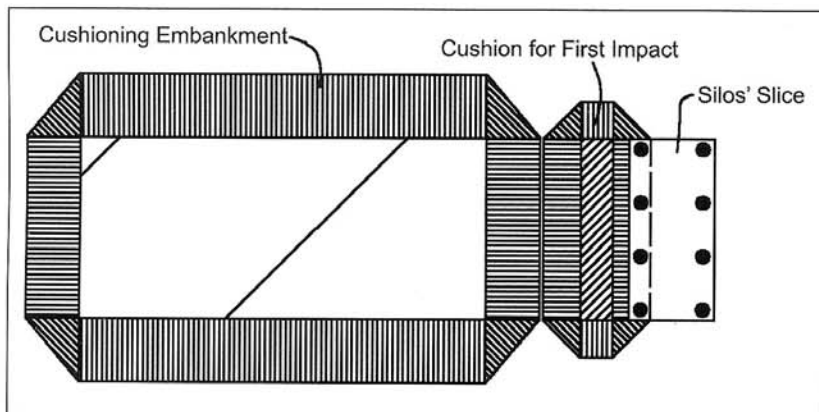
Phase Two Motion Model.

- **Phase Three** starts with the impact on the gravel cushion and ends with the end of the motion of the moving mass. $0 \leq \theta(t) \leq \gamma$



Phase Three Motion Model.

By running these equations we get an average thickness of the gravel and debris cushion of about 4 meters (13 feet) and an impulse of the dynamic stress of 0.5 seconds with a pressure between the lower layer of the gravel cushion and the pier of 3 kg/cm², a value that was compatible with the mechanical resistance of the ground. This stress was applied to a FEM model of the wharf consisting of a 50 x 50 cm mesh (20 x 20 inches) for a total of 4221 solid elements, in order to simulate a part of the pier structure of 100 x 20 meters (330 x 65 feet) with a depth of 10 meters (33 feet). This analysis gave the result of the dynamic stress induced by the fall of each silos' slice, a velocity in the most stressed part of the structure of about 70 mm/s. The information gathered from this study led to the design of the cushioning embankment that apart from the first one, was created with the rubble of the previous demolition, and shaped as shown in the following top view:



Top view, cushioning schematic.

Monitoring Explosive Dust

Before operating with any tool or machine that could generate sparks or excessive heat, we needed to verify the presence of a potentially explosive environment

inside the closed chambers of the silos.

This is a typical danger connected with the processing and storage of grain. Two different potential dangers can exist: one connected to the fermentation of the organic material and one with the dust generated by the grain and in suspension in the air.

In the first case the environment could have been influenced by humidity or water seepage while in the second case, on the contrary, the environment would have to have been completely dry.

With cereal micro-dust in a dry room we have the combustible in suspension, and the combination of air oxygen and a spark can initiate the combustion process that can evolve into an explosion.

The risk of explosion is inversely proportional to the granulometry (dust mean dimension) of the suspended dust, generally the smaller the size of the dust, the higher the possibility that it stays in suspension in a correct mix with air. Previous studies indicate that dusts under 74 microns in diameter are potentially dangerous. Concentrations are in general considered dangerous when between 10 and 600 g/m³ (0.001 - 0.3 lb/ft³). The same explosive situation can be generated by the fermentation of the grain that generates flammable elements such as methane or sulphuric gases, creating an even worse condition than the previous case. In the case of Genoa's silos, both of these situations could have been possible, since the silos, an old multi-cellular structure near the sea, used to contain wheat, and were unused for more than 10 years. Therefore, extensive monitoring had to be carried out in the more than 100 chambers of the silos. The explosiveness of the atmosphere was tested using a multi-gas monitor that tests the concentration of CO₂, CH₄, O₂, CO and H₂S simultaneously. Each chamber being more than 50 meters (160 feet) high was tested in many different positions and the results were always negative.

The concentration of the dusts was tested using a calibrated high volume air sampler. To characterize the dimension of the dust in suspension, a laser diffraction device was used as a particle sizing system. The sample is illuminated by a visible wavelength laser, the particles scatter some light at angles, which are characteristic of their size, forming a series of annular diffraction rings from which a detector and a computer can derive the original particle size distribution. The dust was in the range of potential danger in relation to its size and even if the concentrations measured were always in the safe range, as they can vary in different positions inside the chambers, all the chambers were, previously to any intervention, ventilated and washed by sprinkling with water.

The Diamond Wire Cuts and the Excavators

The extraordinary work with the diamond wire consisted of using a wire 180 meters long (200 yards). To complicate things, the small space around the structure forced us to put the traction pulleys in an orthogonal position respect to the cutting surface. The diamond wire

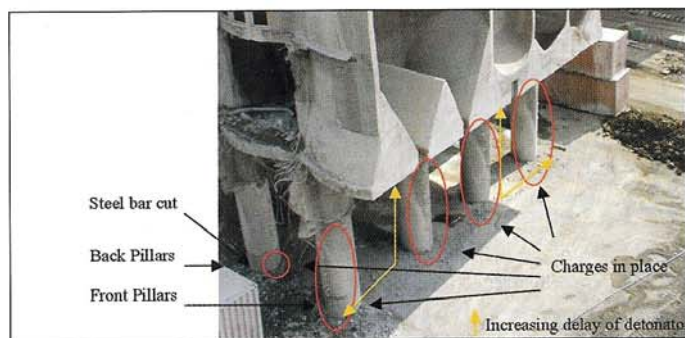


had to cut as much as five reinforced concrete walls simultaneously with heights up to 60 meters (70 yards). A specific electronic device had to be designed and built in order to withstand the massive current peak needed to start the rotation of the wire. Moreover, the room on the top of the silos contained all the mechanical devices and conduits needed to move the grain. These all had to be cut using an oxyhydrogen flame. Since the slices were ready to fall prior to each explosion, the gravel cushions had to be created and that involved a team of 60 ton caterpillar excavators working for several days before each shot.

The Explosives

After the cuts, we had nine separated and similar portions of the silos, each with 8 pillars of 1.5 meters in diameter (5 feet) at the base, in two rows of four pillars each. In order to let the structure fall in the desired direction, the four front pillars had to be loaded with explosives.

The explosives used, as often with concrete, was dynamite in 25 mm (1 inch) cartridges, 200 mm long (8 inches), inserted in 32 mm (1.25 inch) holes drilled with pneumatic drills. Six holes were drilled in each of the front pillars and given the diameter of them, the holes were spaced 80 cm (31.5 inch) apart, resulting in a powder factor of 0.3 Kg of dynamite for m^3 (0.51 per yd^3). A light intervention was designed for the back pillars as well. A hole with a small charge in the frontal part as well as cutting of the vertical reinforcing steel bars in the back of each pillar was used in order to facilitate the rotation of the structure on the base of those pillars. Each hole had a single dedicated electric detonator, 12 different micro-delays in steps of 25 milliseconds were used. The two central pillars were shot first, symmetrically, starting from the base, followed by the two lateral pillars, a 0.5 second delay was used for the holes in the back pillars. Every hole in a pillar had a different delay in order to have the smallest possible cooperating charge and no external detonating cord was used to avoid unnecessary, excessive air blast noise.



During the project, the demolition team was also asked to use explosives to demolish the two adjacent enormous crane-like metallic structures that served to pump the grain from the cargo-boats to the silos. Both structures were standing on several metallic supports up to 2.5 cm (1 inch) in width, all different from each other. It was decided to overturn them on the inside of the wharf using linear shaped charges to cut their stands. A number of linear shaped charges of different weights, ranging from 200 to 450 grams (6 to 16 ounces) per meter, were prepared using NSP.

The massive control tower was the last act of the demolition, after all the slices had been demolished it was the only thing left on the pier, standing like a little 80 m (260 feet) high skyscraper. Being a standard multi-floor concrete structure its lower floors were blasted with explosives, falling the structure in the same direction of the slices from the silo.



Crane falling.



One slice of the silo falling.



Shows the detail of the silos' reinforced concrete pillars after the shot.

Vibration Monitoring and Analysis

Detonation of the explosive charges, both those internal to the concrete pillars and the external shaped charges, did not exceed the maximum level allowed by local regulations.

However, the highest level of vibrations in this kind of work is produced by the impact of the falling structures on the ground. The need to respect the nearby building, required us to set up a structured network of nine different seismograph stations during the 10 days of demolition. The mass of data registered served also to test the previous FEM analysis, and were used as part of an ongoing study to determine the definition of empirical relations in order to forecast peak particle velocities connected to impact of structures on the ground during explosive demolitions.

The purpose of this study was to obtain an equation that could become useful in the study of the feasibility of a demolition, in particular in an urban environment or any other vibration sensitive environment (Given the age and the architectural value of many buildings in Italy, this situation is quite common), to be used in parallel with the Langerfors and Kihlstrom equation (1967) that forecasts the peak of vibration induced by the detonation of explosives.

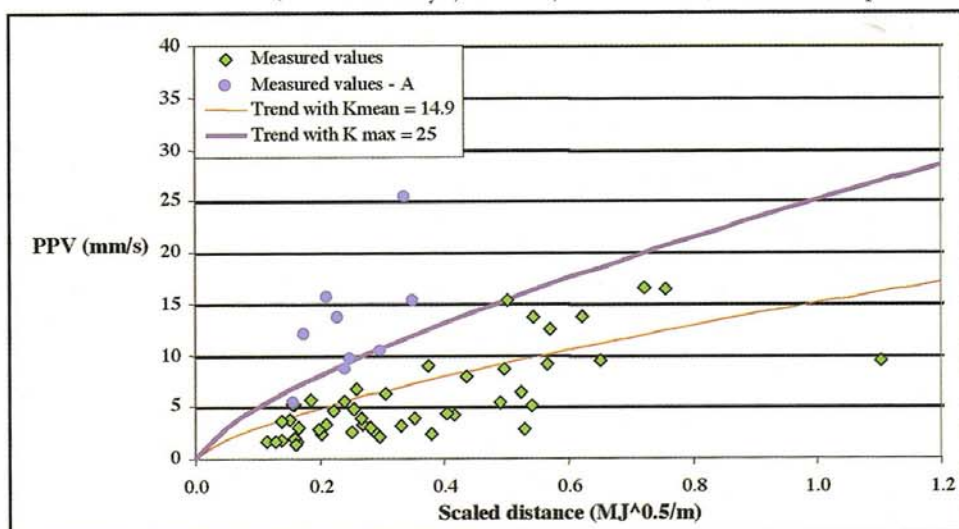
The results of the monitoring were values of PPV always below the Italian regulations (UNI 9916 - DIN 4150) even with some differences in the different days of monitoring given mainly by the non uniformity, in the ten shots, of the gravel cushion prepared, thus confirming its importance in order to reduce vibra-

tions and the need for all preparatory studies to be made.

The empirical relation used to forecast maximum PPVs in a given position produced by the impact on ground was:

$$v = K \cdot \left(\frac{\sqrt{E}}{D} \right)^{0.7078}$$

where E is the potential energy of the falling structure $E = m \cdot g \cdot h_g$, with h_g the height of the center of mass of the main portion of the structure, D is the distance from the impact point, and K is a coefficient function of the characteristics of the ground. K has a mean value of 14.9 and a maximum value of 25. In estimating PPVs using 25 is more conservative. It is important to note that this relation is built upon results of lateral falling structures (like chimneys, towers, "slices" etc.) and not implosions



and that does not take into account any kind of absorbing cushion.

In the case of the silos, the results showed that 90% of the measured values were under the $K=25$ line, and 60% of the values were under the $K=14.9$. By observing a graph of the measured values, it is possible to notice that they follow quite well the K mean value line that coincides

with the regression line of previous measurements and that only values from one seismograph (called "A") are over the curve with maximum coefficient ($K=25$). This was probably due to the peculiarity of the structure, on the edge of the wharf, where the instrument was positioned.

In general, the values were overestimated by the formula, but considering that it does not take into account the effect of the cushion, it is possible to say that comparing the estimated values with the real values, we get an indication of how good the cushioning has been. And, being not possible for several reasons to build ten identical gravel cushions, it has been observed on site that the overestimation was maximum in the days with the biggest cushions and minimal in the days where the cushioning was smaller, therefore confirming the effectiveness of the formula itself.

A final consideration about this formula, derived from both this demolition and previous ones, was that $K=25$ works well to identify a maximum value for tall falling structures, and that it considerably overestimates PPVs in the presence of a cushioning of any kind and that it does not overestimate a concentrated impact in respect to a distributed one. With an increasing number of measurements it will hopefully be possible in the future to better evalu-



ate how these variations influence the formula and identify adequate coefficients to take them into consideration.

Conclusion

Demolitions are often considered, as an activity, inferior to construction. But nowadays as structures to dismantle are getting bigger and more complicated, and safety is a must, it is not possible to improvise anymore. Challenging projects need an accurate design and precise preliminary studies as well as constant monitoring as projects proceed to obtain outstanding results. Demolition is becoming a high technology and structured activity as well as construction.

By using explosives, supported as seen by other different technologies, the demolition of Genoa's silos was concluded successful in a minimal amount of time and with reasonable costs. No one was injured during the project and the surrounding buildings were perfectly preserved. And for the city of Genoa, the discomforts were limited to a bit of dust once a week for a couple of months, but the panorama is now much improved.

About the Authors: Danilo Coppe is the founder and president of Siag, and the most experienced in Italy in explosive demolitions. Andrea Reggiani is a structural engineer and project manager at Siag. Adolfo Bacci is professor of gas dynamics at University of Pisa, Italy. Amanda Vernò is an engineer specialized in vibrations monitoring and control.

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