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SEISMIC VULNERABILITY ASSESSMENT OF A MILITARY DRY DOCK IN MESSINA

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ABSTRACT

The paper summarizes the studies conducted on the military dry dock in the Port of Messina (built in 1861), to assess the seismic vulnerability.

For this work was conducted an accurate research on the historical sources of Technical Office of the Italian Civil Engineers, to know the construction methods, the operations made after the earthquake of 1908 and to increase the size on 1950.

Studies have included the implementation of a finite element model for seismic analysis and with a simulation of construction stages.

The analysis results are evaluated against mandatory italian design code to assess the seismic vulnerability of the structure.

Keywords: dry dock; seismic vulnerability; earthquake; numerical analysis

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1. INTRODUCTION

The arsenal is defined as a few complex establishment of mechanical and marine plants in order to build, repair and maintain Navy vessels, including all the weapons and equipment owned. Besides including ports and docks, a maritime arsenal includes all sorts of workshops, experimental laboratories, warehouses and office management and administration as well. The idea of naval arsenal was conceptually born during the Arab period, probably as a process of evolving environment in old formulas dating back to classical antiquity.

From the sixteenth century and to the present day, historians, writers, chroniclers and scholars of Messina have always taken for granted that Messina, since the beginning of its history, had a large arsenal - "the most important in the Mediterranean" . This theory was justified by many resources of city's history: the city had a strong seafaring and commercial vocation and was in the center of the main maritime trade for a couple of millennia, being a compulsory transit point on the busiest routes.

There is a gravity type dry dock inside the Military, called "Bacino in Muratura", in use today in by the Agenzia Industrie Difesa "Militarsen" of Messina. According to the chronicle it was built by the Genio Civile with many difficulties.

A campaign of surveys carried out in 2003 revealed a stratigraphic sequence of unusual heterogeneous material elements in the quoin of the internal dock, used during the realization possibly in order to counter water and slime infiltration emerged during the excavation.

The stone cladding (thickness about 80 cm) rests on a pozzolanic conglomerate (about 70 cm) constructed as a water infiltration barrier on the base slab.

Two rows of bricks found along the vertical direction were used as a subbase for finished paving and for the foundation slab (thickness of about 4.00 m). The pozzolanic mixture used (lime, crushed stone and pozzolana) was poor in pozzolana and rich in lime, therefore used as a binder of gravel and other inert material. The obtained composite that does not show its mechanical fatigue resistance and properties allows water filtration compromising the correct execution of the work. Today this area shows the same problems.

This structure suffered severe damage by the famous earthquake in 1908, with the natural consequence of inactivity of the basin up to 1911.

The new structure was built about 1.70 m off-axis relative to the first one. The slab was investigated in the 2005 campaign that highlighted the consistency (thickness of about 5 m) and good structural quality. It rests on a layer of stones vary depending on a concave surface upward from 0.90 to 1.80 m. The walls of the "new reservoir" are covered with blocks, packed with the natural conglomerate (polygenic conglomerate – in slang pudding) found and remove during the excavation using mines.

The extension does not have exhaust galleries, which are present in the section of "old dock", but contains drains and pipes laid under the extrados'slab.

In 1976, the Genio Civile realized the last important reinforcement for the basin. The area of the gargame was covered with plates of 15 mm with tie beams in the front of North and South input threshold.

2. HISTORICAL FRAMING

The seismic vulnerability assessment has been carried out on a military dry dock located inside the Messina naval shipyard. The first building structures and the first activities date from the roman period and had a strong development during the Arabian domination in Sicily. From the urbanistic point of view, the complex of structures is located in a well defined area, detached from the city, and is provided with suitable defensive works to protect military activities.

As military shipyard; the dry dock construction was carried out few years after The Italian Unification. In that period there was an increase in size and tonnage of the ships – supported with the use of steel technologies in the ship construction and of steam engines - and therefore the need to set up a suitable area to be equipped for the maintenance of military and merchant ships raised up.

So Civil Engineers offices planned the project and the structural works started on 1869. On 1876 the dry dock construction was completed.

The dry dock, planned as a large basin 104 m in length and covering an area of 21500 m^2, worked without interruption until 1908 when the well known earthquake of Messina damaged the structure of the dock closure device: the dry dock was flooded and a ship that was there in maintenance sank. After restoration and safety works, the dry dock started work again on 1912.

After the Second World War, with the development of national economy, with the increasing of ship traffic and the use of large size ships, the need to enlarge the dry-dock raised up. So the dry dock have been lengthened of 50 m. On 1954 all construction works have been concluded.

2.1 The construction technique

The dry dock in Messina, named “at gravity”, is one of the first examples planned in Italy with this kind of technique. Unfortunately the original documentation of the dry dock project drawn up by the two worker directors, F. Damiani and G. Medici engineers, was nowhere to be found. Only a descriptive information referred to the object it has been possible to find in the text drawn up by general F. Martini focussed on the latest construction of dry dock in the Venice naval shipyard.

The available information evidences that the excavation, having sides with a slope of about 45°, has been made applying open cut techniques. Explosives were used to cut the polygenic conglomerate (pudding), located 60 cm below the ground level.

The following construction of the dry dock structure, has been probably carried out using a mobile bridge where lines were overlapped to permit the movement of the vehicles used for conglomerate transportation (Figure 1). Finally, filling material was used to fill up the hollow space between the structure and the rock.

The walls and the bed of the dry dock have been probably made with pozzolanic material, sand and gravel aggregates, adding hydrated lime as binder material.

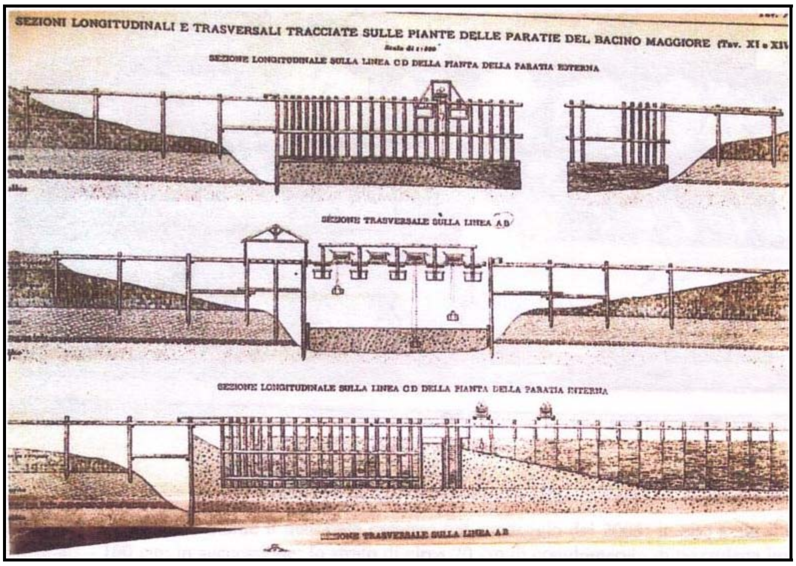

Figure 1. Structural scheme of a dry dock and the provisional work necessary for the realization phase

3. GEOLOGICAL AND GEOTECHNICAL FRAMING

The area, when dry dock was realized, is characterized by a narrow peninsula which start to the cost of arching in the sea off Messina thus creating a protected natural dock for landing of ships (Figure 2). The deposits in this area were subjected at different survey campaigns, especially in recent years (September 2005 and July 2009), in order to get a precise characterization of the subsurface near the dry dock.

Figure 2. Aerial view of Messina with the identification of the port (left) and of the dry dock within the port (right)

2.2 In situ soil tests

The study of soils characteristics around dry dock was conducted through appropriate prospections carried out near the dock. With reference to the construction technique described above, the investigated area is approximately identified with the upper backfilling of the side walls of dry dock.

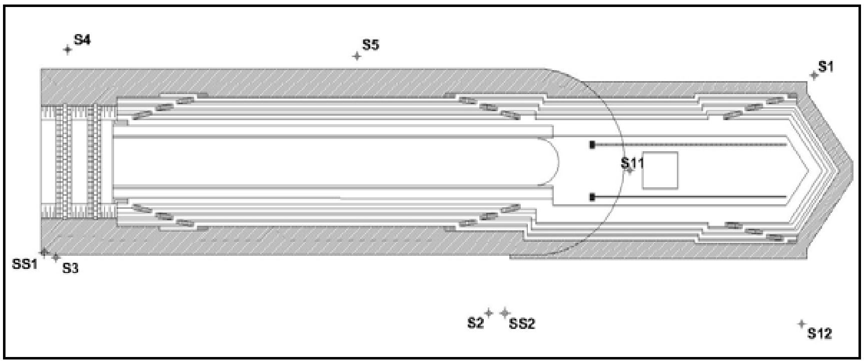

Figure 3. Dry Dock planimetry with the points of investigations execution

Particulary, in 2005 were performed geophysical prospections including:

- n°2 eletrical resistivity tomographies for total length of 112.50 m, placed in the left side of the dry dock (looking from the sea) for the valuation of apparent resistivity;
- n°1 seismic tomography placed in the same area of the eletrical tomografy for lenght of 85 m for the valuation of seismic wave velocity;

Besides tomographies were also performed n°7 mud drillings to execute SPT (Table 1).

Table 1: SPT results

drilling	*depth*	*N1*	*N2*	*N3*	N_{spt}
	[m]	*[/]*	*[/]*	*[/]*	*[/]*
SS2	16.50	10	9	11	20
S3	14.50	6	6	6	12
S4	8.50	7	6	6	12

After, in 2009, were performed other geological, geophysical and geotechnical investigations:

- n°2 drillings one of which near loading dock (SS1) and the other to subsoil investigation in the right side of the dry dock (looking from the sea);
- n°1 MASW on the floor of dry dock for the acquisition of seismic profile.

The investigations around dry dock have demonstrated the alternation of three lithologic units with different geomechanical characteristics:

- backfill consisting of silty sands with gravels and anthropically reworked materials;
- fine sands and silts;
- gravels and coarse sands.

2.3 In situ conglomerate tests

The study of the characteristics of conglomerate, with which it was made the dry dock, was performed during the same investigations for the geomechanical characterization of soils. In particular have been performed 5 drawings from which they are subsequently 15 test pieces. The results are show in Table 2 while in Figure 4 are identified the points of investigations execution.

Table 2: Compression tests results on conglomerate

drilling	***Structural element***	***n° drawings***	$f_{opera,\,m}$	f_{ck}
			[MPa]	*[MPa]*
CP1	Floor of "gargame"	3	9.00	2.58
CP2	Floor of old dock	3	6.50	N.D.
CP3	Floor of new dock	3	30.20	27.53
CP4	Old dock walls	3	41.20	40.48
CP5	New dock walls	3	16.70	11.65

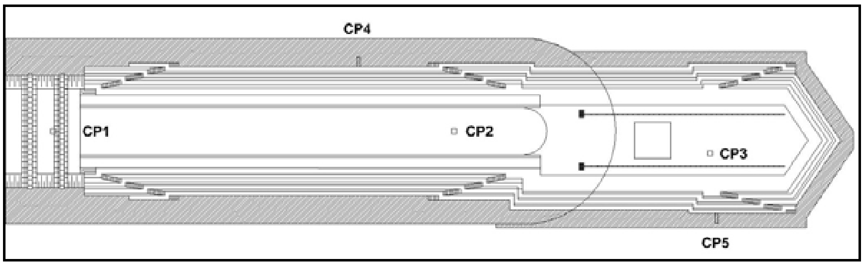

Figure 4. Dry Dock planimetry with the points of investigations execution

4. NUMERICAL ANALYSIS

The study on the seismic behavior of the dry dock has been carried out, both in static and dynamic condition, with the finished element analysis.

The particular shape of the dry dock has allowed to treat deformations of the BB and CC sections (Figure 5), named "old dry dock " and "new dry dock" respectively, in flat condition. Otherwise, taking into account the surround and charge conditions, to the AA section, named "*gargame area*" a tridimensional model has been applied.

The BB section, named "old dry dock", is characterised by the presence of drainage galleries

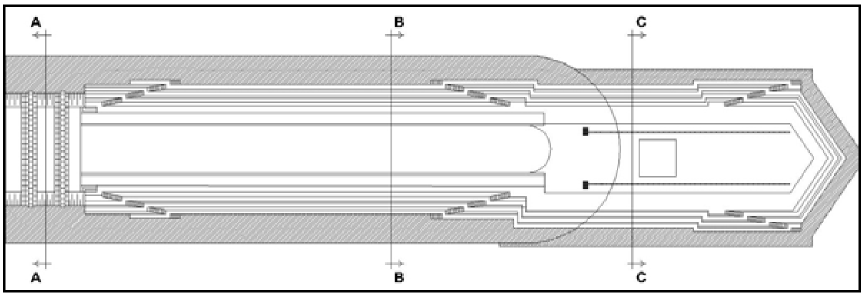

Figure 5. Dry dock planimetry, where the main studied sections are shown

Section CC, named “new dry dock”, takes into consideration the dry dock lengthening carried out in the fifties, during the last century. This section is characterized by a foundation with a concave upward shape in the extrados and by the absence of drainage galleries.

Section AA, named “gargame area”, shows the dry dock entrance. This section is characterized by the absence of a backing arch, to reinforce the beaten seats where the ship-door is scarfed. The absence of this backing arch, generally present in other dry docks (among these, the “twin” in La Spezia), induces a high stress on the foundation that shows severe swellings under the closure site. To temporarily solve the problem a number of concrete blocks have been positioned on the foundation. Moreover the zone has been reinforced applying steel plates anchored with ties to the sides of the dry dock.

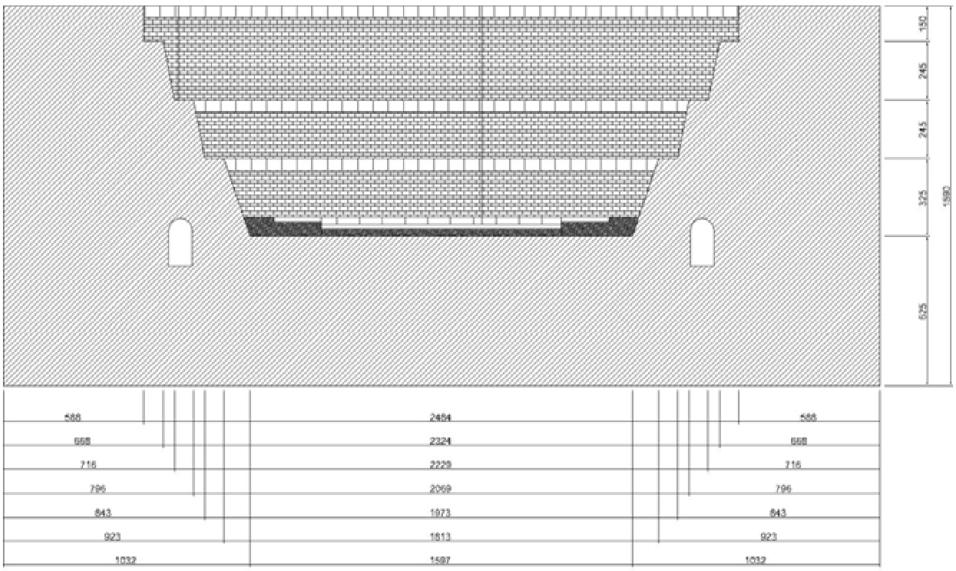

Figure 6. Section BB, named “old dry dock”

Section CC, named “new dry dock”, takes into consideration the dry dock lengthening carried out in the fifties, during the last century. This section is characterized by a foundation with a concave upward shape in the extrados and by the absence of drainage galleries.

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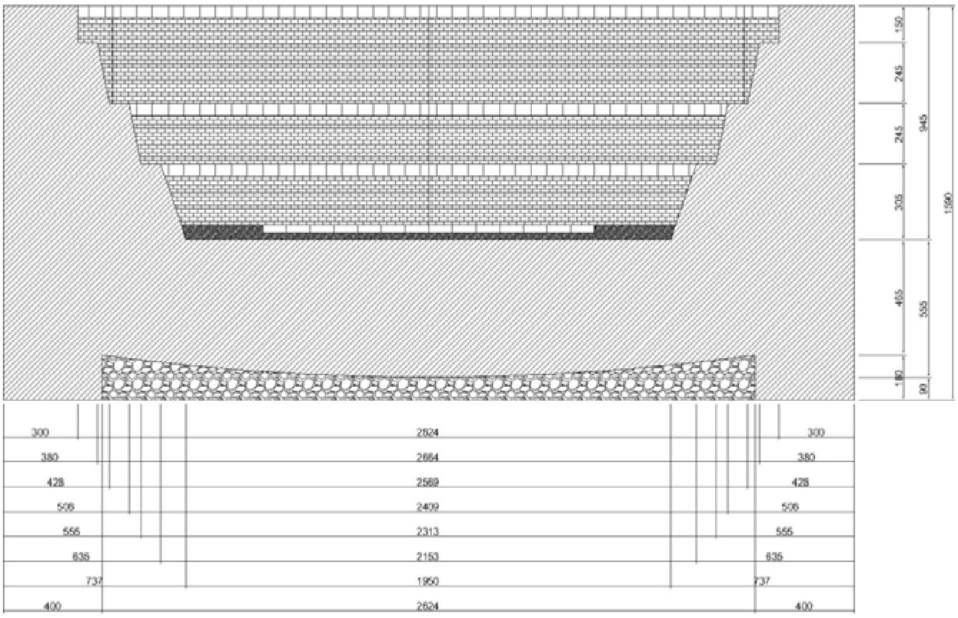

Figure 7. Section CC, named “new dry dock”

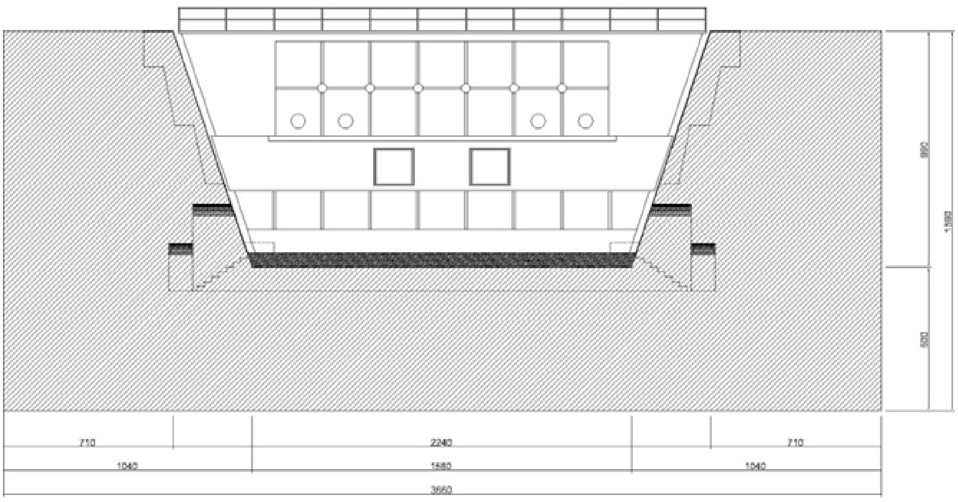

Figure 8. Section AA, named “gargame area”

4.1 Acting loads

The study of loads acting on the boundary involves the application of:

- load on the square equal to 40 kN/m^2, present in all the section, due to sheds and structures present at the boundary of the dry dock and to the weight of the material used during maintenance of ships;
- load due to the presence of a crane on the right shoulder (looking from the sea) that moves on tracks (132 m length, gauge 6 m, 12 m race start from front bulkhead). The load equal to 30 kN/m^2 has been determined according to the drawings of the supplier;
- Load due to the static pressure distributed over the entire length of the dry dock exerted by the presence of the ship, the charge is transmitted on the foundation floor by the docking blocks (each one 1 m large), arranged as in Figure 9, and for each of them is equal to 135 kN/m^2. Considering 3 docking blocks, the total charge in the generic section is about 400 kN/m^2;
- seismic load due to the presence of the mass of the ship;
- overload due to the presence of concrete blocks in gargame area (modeled as pressure loads, both static and seismic). For those blocks a mass equal to 2300 kg/m^3 and 1 m height was considered.

It should be underlined that the latter load was applied only to evaluate the improvement of operational conditions and to evaluate the benefit made in relation to problems of swelling of the boat-door described above for the AA section.

In addition, an aquifer located approximately 1 meter from ground level, which is the floor of the wharf, was considered.

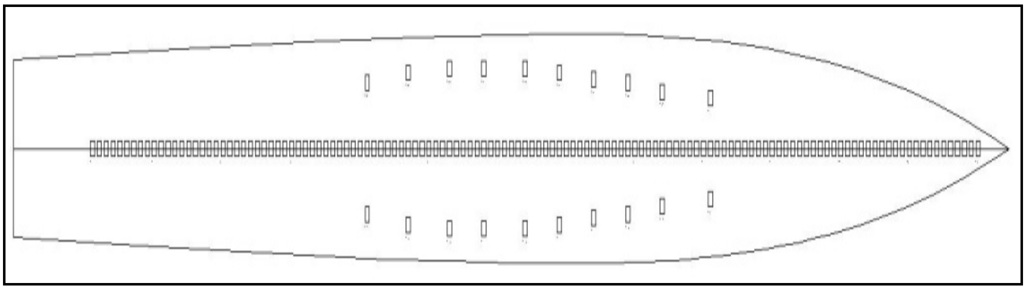

Figure 9. Example of docking blocks arrangement

4.2 Definition of mechanical specifications of ground and conglomerates

4.2.1 Static analysis

Geological studies and investigations carried out for the *Agenzia Industrie della Difesa (AID)*, described previously, have led to the definition of the geomechanical characteristics of soils to be used in static analysis. The following is a summary table (Table 3) containing all data inherent this characteristics. Table 4 contain a different typologies of soils identified in the sections to be used for numerical analysis.

Table 3: Geomechanical specifications of soils around dry dock before and after the implementation.

Soil Type		γ	ϕ	c	E	ν
		[kN/m^3]	[°]	[kPa]	[MPa]	[/]
Before the construction	***Polygenic conglomerate "pudding"***	17	45	350	250	0.08
After the construction	***Backfill***	14	22	0	2	0.3
	Fine sands and silts	16	30	0	5.25	0. 3
	Gravels and coarse sands	18	33	0	34.7	0.3

Table 4: Typologies of soil in the sections after the dry dock construction

Soil Types	***Section AA***	***Section BB***	***Section CC***
Backfill	0; – 3.95 m	0; -6.4 m	0; -3.95 m
Fine sands and silts	– 3.95 m; -15.90 m	-6.4 m; -9.65 m	-3.95 m; -15.9 m
Gravels and coarse sands	under	-9.65 m ; -15.9 m	under

Through the interpretation of the tests performed during the same geological investigations, has also been performed to the characterization of the conglomerates with which it was made the structure of dry dock. The mechanical specifications, to be used for numerical FEM analysis, are summarized in Table 5.

Table 5: Mechanical specifications of the conglomerates when which was made the structure of dry dock.

Conglomerates types	γ	E	ν
	[kN/m^3]	[MPa]	[/]
Floor of old dock	18	10000	0.10
Floor of new dock	24	32000	0.15
Old dock walls	23	39000	0.15
New dock walls	22	21000	0.15

4.2.2 Dynamic analysis

The seismic characterization of soils around the dry dock was performed considering the modulus of elasticity and the shear modulus resulting from the Ohta & Goto's (1978) correlation with the V_s (shear wave velocity) value and the result of Standard penetration tests (SPT).

$$V_s = C \cdot (N_{60})^{0,17} \cdot (z)^{0,2} \cdot f_a \cdot f_g \qquad [m/s]$$

where:

C = 68.5 costant

$N_{60} = N_{spt}$*(ER/60) ER/60 = 1,08; N_{60} = SPT number of blows normalized with respect an efficiency equal to 60%

z = depht in m

f_a, f_g = corrective factor taking into account the age of formation and the influence of rate of deformation.

Through the value of shear wave velocity is possible to calculate the shear modulus "G" and the modulus of elasticity "E", for dynamic conditions, whereas:

$$G = \gamma \cdot V_s^2 \qquad [MPa]$$

$$E_d = 2 \cdot G \cdot (1+\nu) \qquad [MPa]$$

where:

γ = total unit weight;

V_s = shear wave velocity;
ν = Poisson's ratio.

The results of the analysis are show in the following table (Table 6).

Table 6: Modulus of elasticity and shear modulus of soils used during seismic analysis.

Soil Type	***G***	***G/3***	***E***
	[MPa]	[MPa]	[MPa]
Conglomerate	849	283	736
Gravel	90	30	78
Sand	55	18	37
Backfill after excavation	41	14	27
Backfill before excavation	16	5	14

Same method was adapted for the characterization of conglomerates of the structure. For these structure has been attributed a velocity shear wave equal to 3000 m/s, permissible value for an average compacted concrete (Table 7).

Table 7: Shear wave velocity, modulus of elasticity, shear modulus of conglomerates used to analysis and subsequent testing.

Conglomerate Type	V_s	***G***	***G/3***	***E***
	[m/s]	[MPa]	[MPa]	[MPa]
Floor of old dock	3000	16514	5505	12110
Floor of new dock	3000	22018	7339	16881
Old dock walls	3000	21101	7034	16177
New dock walls	3000	20183	6728	15474

4.3 Definition of seismic input

4.3.1 Response spectrum analysis

The definition of seismic input depends on the intrinsic characteristics of the structure that is, its strategic importance that the same assume for the activities for which it was made. For this reason, whereas the strategic importance of this structure both in the contest of military as well as civil, the definition of response spectrum (Figure 10) provides the use of the parameters show in Table 8.

Table 8: Response spectrum parameters.

Stato Limite	SLC		
Vita nominale	V_N	[anni]	≥ 100
Classe d'uso	[/]	[/]	III
Coefficiente d'uso	C_u	[/]	1.5
Periodo di riferimento	V_R	[/]	150
Probabilità di superamento	P_{VR}	[%]	5
Coefficiente topografico	S_t	[/]	1.00
Coefficiente stratigrafico	S_s	[/]	0.92
Accelerazione del sito	a_g	[1/g]	0.485
Accelerazione massima	a_{max}	[1/g]	0.446
Fattore di struttura	q	[/]	1

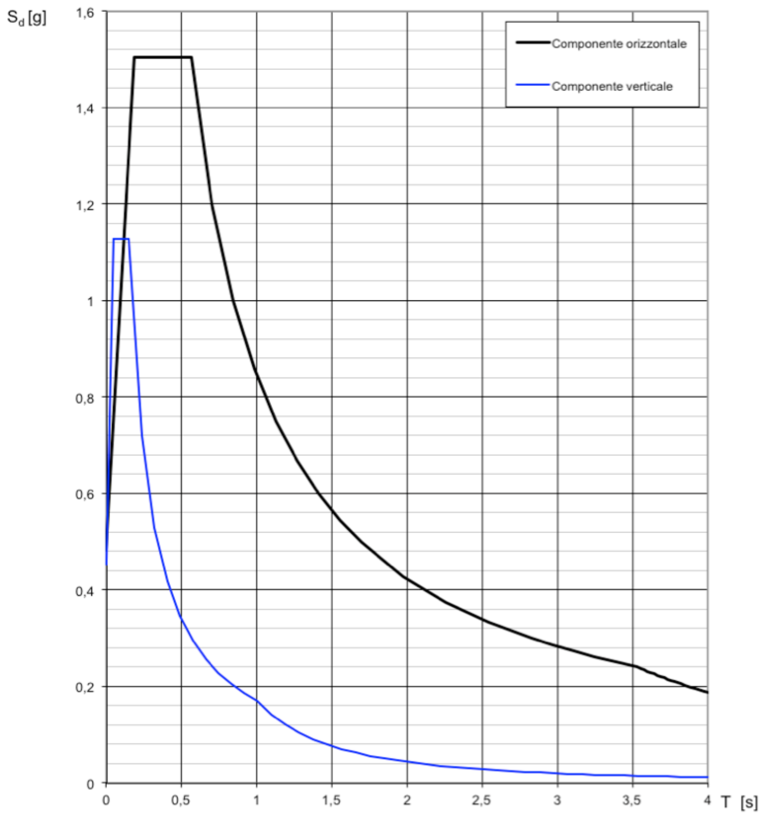

Figure 10. Response spectrum for the vertical and horizontal components

4.3.2 Step by step analysis

The study on the seismic behavior has also been carried out with "step by step" analysis, through direct integration of the equation of motion in time domain and for the entire duration of the ground motion (20 sec.). The choice of integrating for the entire duration of the ground motion was necessary to verify the behavior of the structure under consideration during the whole time interval in question.

Regard to ground motions used in the analysis, is well to specify that these are generated in an automatic, thought appropriate software, in order the meet the regulatory compliance requirements for chosen response spectrum and previously reported (Figure 10).

The analysis was conducted by combined application of spectrum in the three principal directions through the use of more the one set consisting of three different ground motions, one for each main direction, in order to reconstruct the 3D state of stress.

4.4 Results

4.4.1 Static analysis

The static analysis has shown that the dry-dock structure has a characteristic behaviour similar to a double supporting wall under water-bed.

The stress conditions on the structure have been evaluated with "the construction stage analysis" taking into consideration all the main phases historically involved in the dry dock construction. These steps can be summarized as follow: starting conditions, starting excavation, ending excavation, foundation floor execution, walls execution, backfilling, ship placement.

In the last stage of the analysis, the presence of the ship in maintenance has been simulated with a rigid structure supported on the actually used three docking blocks, of well defined size and position, realized on the bed of the dry dock.

AA section – "gargame area"

Taking into account the geometry and the charge conditions, a 3D model has been applied to this section (Figure 11). Table 9 shows the obtained results as stress condition and displacement. These results evidence that, on the longitudinal direction to the dry dock (the "z" axis) in the point "A" of contact section, the bending stresses induce tensile stresses of about 0.3 MPa. This value is very close to the maximum tensile stress of the pozzolanic conglomerate used for the foundation floor. The load condition examined here provides for the absence of the ship, since this area is always left free from obstructions for the boat - door opening and the handling of ship maintenance materials, the absence of any counterweight on the foundation floor and with yard load , excepted the crane.

Considering the state of effort evaluated in the point "B", the intrados of the foundation floor, it has confirmation of bending stress established in the section which generates a compression, albeit very low.

As regards the status of stress in horizontal direction transverse to the dry-dock (the "x" axis), the state of stress is still likely to generate a bending stress, similar to that obtained for section BB, "old dock" whose results are reported in the following paragraph.

In conclusion, despite most of the volume of conglomerate in this area of the dry-dock is subject to widely acceptable compression stresses, the foundation floor of the gargame area is very damaged, so concrete blocks, acting as counterweights, have been used to stabilize the bulge of the foundation floor.

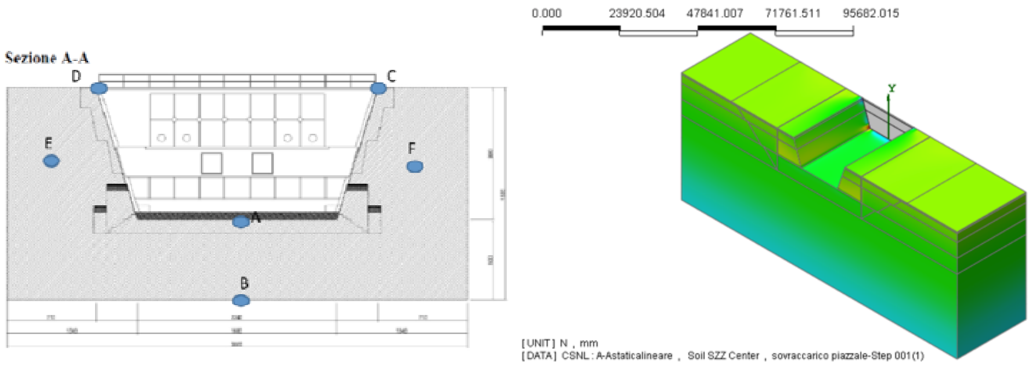

Figure 11. Section AA, named gargame area

Table 9: Static analysis.

Points	without blocks					
	Dx	**Dy**	**Dz**	**σxx**	**σyy**	**σzz**
	[mm]	[mm]	[mm]	[Mpa]	[Mpa]	[Mpa]
A	-0.089	-1.022	7.255	0.310	-0.277	-0.577
B	-0.094	-2.830	0.040	-0.367	-0.314	-0.207
C	0.450	-6.541	2.249	0.246	-0.041	-0.415
D	-0.898	-6.243	2.250	0.246	-0.040	-0.407
E	0.950	-8.840	4.927	-0.514	-0.145	-0.045
F	-1.264	-9.215	4.927	-0.045	-0.143	-0.045

Otherwise, the problem does not occur on the shoulders of the dry dock where, in recent years, has been reinforced applying steel plates anchored with ties to the structure

Section BB – “old dry dock”

Section BB, named “old dry-dock”, is characterized with the presence of two drainage galleries. Figure 12 shows the studied section and the points where displacement and stress state have been determined. These values have been listed in table 10.

As can be seen from table 10, in dry dock condition (without water inside), with the presence of the lifting force exerted by the aquifer, of the yard load and of the crane but in the absence of the ship, the State of deformation of the dry dock generates a state of compression stress both at the intrados that at extrados. However values are very different between them, this means that there is a kinematic state that tends to cause the “opening” of the dry dock and to dismiss each other points "C" and "D".

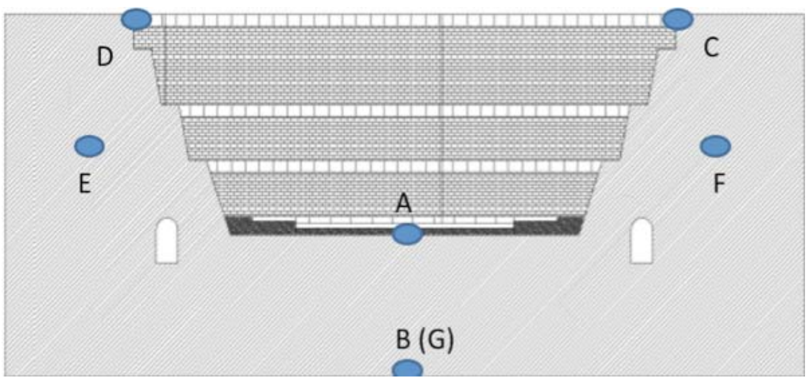

Figure 12. Section BB, named “old dry dock” with the localization of the points where displacement and stress state (values listed in table 10) have been determined. It is necessary to underline that the "B" point refers to the extrados of the dry-dock while the point "G", coincidental, refers to the end of excavation before the foundation floor was realized.

Otherwise, the condition in which there is the simultaneous presence of the ship and of all other loads, induces the rebalancing of the kinematic mechanism described above with a subsidence movement of about 10 mm.

The numerical analyses carried out clearly demonstrate that throughout the conglomerate of this section only punctual and modest tensile stresses have been evidenced.

Table 10: Static analysis: displacement and stress state values determined in the main point of section BB “old dry dock”.

Points	without ship				
	Dx	**Dy**	**Dxy**	**σxx**	**σyy**
	[mm]	[mm]	[mm]	[kN/m^2]	[kN/m^2]
A	0.0	-3.6	3.6	-285.5	-4.7
B	0.0	-4.5	4.5	-424.8	-154.7
C	1.3	4.0	4.2	0.5	-6,6
D	-1.0	4.3	4.5	0.2	-7.0
E	-0.5	7.5	7.5	-54.5	-104.6
F	0.7	7.1	7.1	-57.9	-154.7
G (end of excavation)	0.0	2.8	2.8	47.1	-2.5
	with ship				
	Dx	**Dy**	**Dxy**	**σxx**	**σyy**
	[mm]	[mm]	[mm]	[kN/m^2]	[kN/m^2]
A	0.0	-10.4	10.4	-871.4	-399.0
B	0.0	-11.2	11.2	67.0	-230.0
C	-0.9	-1.3	1.6	0.5	-6.5
D	1.2	-1.0	1.6	0.2	-6.9
E	0.8	2.5	2.7	-51.3	-115.3
F	-0.7	2.1	2.2	-52.8	-113.4

Section CC – “new dry dock”

In the section CC, named new dry dock, where drainage galleries are not present as in the previous section BB, it is possible to note how the extrados of the section CC has a curved shape with upward concavity.

The figure 13 shows the studied section and the points where displacement and stress state have been determined. These values have been listed in table 11.

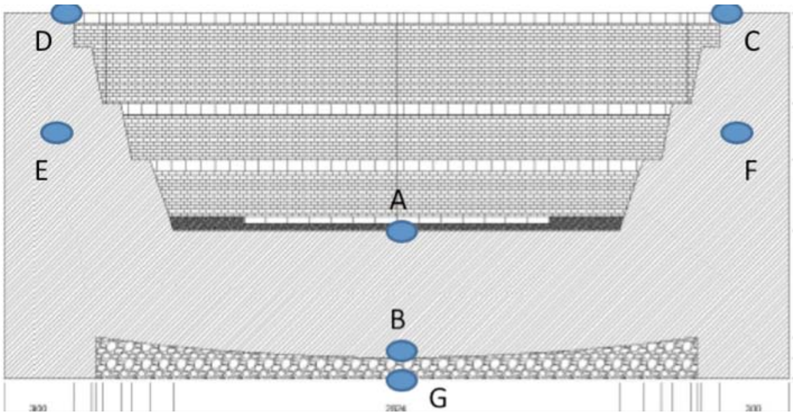

Figure 13. Section CC, named “new dry-dock” with the localization of the points where displacement and stress state (values listed in table 11) have been determined. It is necessary to underline that the "B" point refers to the extrados of the dry dock while the point "G", that here is no coincides with "B", refers to the end of excavation before the foundation floor was realized.

Table 11: Static analysis: displacement and stress state values determined in the main point of section CC “new dry dock”

Points	**without ship**				
	Dx	**Dy**	**Dxy**	**σxx**	**σyy**
	[mm]	[mm]	[mm]	[kN/m^2]	[kN/m^2]
A	0.0	-28.6	28.6	445.13	-6.10
B	0.0	-28.5	28.5	-586.89	-175.48
C	2.1	-15.3	15.5	3.32	-2.27
D	-1.9	-14.9	15.1	2.93	-2.82
E	-0.9	-15.0	15.0	0.74	-146.28
F	1.0	-15.4	15.4	-2.03	-135.87
G (end of excavation)	0,0	3,1	3.1	52.12	-2.51
	with ship				
	Dx	**Dy**	**Dxy**	**σxx**	**σyy**
	[mm]	[mm]	[mm]	[kN/m^2]	[kN/m^2]
A	0.0	-8.6	8.6	-1256.7	-401.6
B	0.0	-8.5	10.2	179.8	-221.7
C	-0.3	6.2	6.2	1.6	-4.5
D	0.5	6.6	6.6	1.2	-5.0
E	0.3	6.6	6.6	-57.7	-97.5
F	-0.2	6.2	6.2	-60.6	-99.9

As can be seen from table 11, in dry dock condition, without water and ship, the state of deformation of the dry-dock generates a state of compression stress at the extrados and tensile stress at the intrados. Also in this situation kinematic motion tends to cause the “opening” of the dry dock and to dismiss each other points "C" and "D". This section suffers an expansion much more pronounced than the previous BB so to register many cracks both on the floor plan and on vertical walls. The cracks along these walls are directed from the top down just to signify the presence of differential movement between the various sections, concentrated mainly in the area of contact between the new and the old dock.

The condition in which there is the simultaneous presence of the ship along with all other loads presents re-balancing of the kinematic motion described above, with a subsidence movement of about 20 mm. This depends on the presence of curved extrados and loads spread over the three points (placement of the docking blocks), which reduces the yield differentials between the various load conditions.

4.4.2 Dynamic analysis, response spectrum

Linear dynamic analysis with "response spectrum" were performed by composing the spectrum along the transverse direction to the sections ("x" axis) with that along the vertical axis (“y” axis) appropriately scaled. In this way the seismic source forcing has been defined according to the following equality:

$$E = (\pm E_x \pm 0.3 \cdot E_y)$$

The analyses were conducted by highlighting the different vibration modes of the structure whose values of vibration periods are given in table (table 12). These analyses were performed on the BB and CC section described above considering the only structure and its its state stress - strain resulting from construction phase.

Table 12: Vibration characteristic of the main vibration

Mode	***SECTION BB***	***SECTION CC***
	[sec]	[sec]
1°	0.50	0.45
2°	0.38	0.37
3°	0.28	0.26
4°	0.27	0.25
5°	0.26	0.23
6°	0.23	0.21
7°	0.19	0.19

4.4.3 Dynamic analysis - step by step

The analyses were performed using the complete integration in the time domain and for the entire duration of ground motion (20 sec.). This analysis involved all three sections before described.

Also in this case the seismic forcing has been defined as required by legislation such as:

$$E = (\pm E_x \pm 0.3 \cdot E_y \pm 0.3 \cdot E_Z)$$

Table 13: Analysis "step-by-step": displacements and stress state difference arising from dynamic analysis "step-by-step", recorded in the remarkable points of the section AA.

Points	Section AA					
	Dx	Dy	Dz	Δσxx	Δσyy	Δσzz
	[mm]	[mm]	[mm]	[kN/m^2]	[kN/m^2]	[kN/m^2]
A	-26.420	-1.560	-0.230	-61.000	-82.000	-24.000
B	-26.090	-1.560	-0.160	56.000	-120.000	-36.000
C	-28.370	-2.000	-0.230	561.000	9.000	-47.000
D	-28.250	-2.080	-0.230	-569.000	-104.000	50.000
E	-27.570	-2.520	-0.280	-47.000	-144.000	3.000
F	-27.580	-2.430	-0.250	-40.000	148.000	3.000

Table 14: Analysis "step-by-step": displacements and stress state difference arising from dynamic analysis "step-by-step", recorded in the remarkable points of the section BB.

Points	Section BB				
	Dx	Dy	Δσxx	Δσyy	Δσxy
	[mm]	[mm]	[kN/m^2]	[kN/m^2]	[kN/m^2]
A	27	-15	18	0	20
B	26	-15	6	0	28
C	31	-15	35	0	0
D	31	-15	3	3	0
E	29	-15	56	64	53
F	29	-16	62	25	60

Table 15: Analysis "step-by-step": displacements and stress state difference arising from dynamic analysis "step-by-step", recorded in the remarkable points of the section CC.

Points	**Section CC**				
	Dx	**Dy**	**Δσxx**	**Δσyy**	**Δσxy**
	[mm]	[mm]	[kN/m^2]	[kN/m^2]	[kN/m^2]
A	26	-15	13	0	16
B	26	-15	-20	0	-31
C	29	-15	4	1	0
D	29	-15	-4	1	0
E	27	-15	23	18	38
F	28	-15	-22	-21	39

Tables 13, 14 and 15 show the results detected as a function of the variation of the time with the analysis step by step in the main points previously indicated.

In the analysis of the sections was identified as critical the maximum stress-strain found in the point "A" (intrados of the foundation plane), that is indicative for the behavior of the dry-dock section.

As it is evidenced from the tables, all sections are subject to increments of stress state of deformation widely compatible with the stress state of the structure, such as to be included in the usual variations resulting from loading-unloading-cycles that occur in each dock activity.

5. CONCLUSIONS

The results of the analysis showed that, under static conditions, the dry-dock structure is able to provide the necessary security for daily operations. However, this security can not be guaranteed for a long time because of poor durability of materials, due to both the "oldness" of the same that the high number of cyclic stress loading-unloading-reloading to which the structure is subject during normal activity of the dry dock.

This is true for the structures of the foundation floor both the old and, mainly, the new dry dock, also paying particular attention to the area of gargame near the boat-door.

Moreover there is the problem of the walls, highlighted by the comparison between the results of the analysis of the different sections analyzed, from which emerge clear the differential shifts that occur between the different sections of the structure.

Looking carefully at the different studied sections, the area of "old dry dock" presents a state of stress largely compatible with the values of strength of materials. In contrast, the structure of the "new dry dock" presents a greater state of stress that on site has been evidenced by the presence of cracks and the consequent water seeping inside.

As seismic conditions, it is necessary to point out that the presence of the ship within the dry dock is, taking into account the technique of positioning and in the light of previous experience (earthquake of 1908), a source of instability.

This statement comes from a reflection on the general conditions of ships and it is not related to the specific case of this dry dock, where the stability of the in static conditions is pursued.

About the structure, the resulting (stress) state not shows excessive stress concentrations.

In short, the current condition of the dry-dock are not such as to affect immediate use. However, this condition cannot be guaranteed for a long period if not restructuring operations will be carried out on well-identified areas to remove the shortcomings of the present materials.

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