CARATTERIZZAZIONE STRUTTURALE DEI COMPONENTI INDUSTRIALI NEL CONTESTO DI ANALISI DI RISCHIO SISMICO

STRUCTURAL CHARACTERIZATION OF INDUSTRIAL FACILITIES IN THE FRAMEWORK OF SEISMIC RISK ANALYSIS

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ABSTRACT

Natural catastrophic events may affect the integrity of industrial structures (equipment, auxiliary system, instrumentation, structural support, utilities). As a consequence, loss of energy or mass or, more generally, both mass and energy from the containment system is likely to occur. If industrial facilities store large amount of hazardous materials, accidental scenarios as fire, explosion, or toxic dispersion may be triggered, thus possibly involving working people within the installation and/or population living in the close surrounding or in the urban area where the industrial installation is located. In this framework, increased knowledge and development of simplified "engineering" tools for the analysis of industrial accidental scenarios in seismic areas are needed. To this aim principal classes of equipment may be sketched as those which can produce relevant issues if earthquake hits an industrial installation. In particular a detailed study on these classes of equipments has been developed to obtain a design and construction standardization in the framework of seismic risk analysis.

SOMMARIO

Eventi catastrofici naturali possono compromettere la sicurezza di strutture industriali (componenti, sistemi ausiliari, strumentazioni, supporti strutturali). Le conseguenze possono consistere nella perdita di energia e/o di massa dai sistemi di contenimento. Queste ultime, se rilasciate in grosse quantità, possono produrre incendi, esplosioni e dispersione di nubi tossiche mettendo così a rischio la vita degli operatori e della popolazione residente nell'area circostante il complesso industriale. In questo contesto, appare necessario lo sviluppo di strumenti basati su metodologie proprie dell'ingegneria, ancorché semplificati, capaci di fornire analisi dei rischi industriali connessi all'evento sismico. Ciò, ovviamente, richiede l'interazione di differenti competenze tecniche e scientifiche e dal punto di vista strutturale evidenzia l'interesse di uno studio dettagliato sui principali componenti industriali, finalizzato a standardizzarli sia dal punto di vista progettuale che costruttivo.

1 INTRODUCTION

Industrial facilities are very complex systems that may require large efforts to ensure safe operations, as they often store large amount of toxic and flammable substances. Hence, the assessment of risks associated to such plants is a key issue, and tools to design prevention and mitigation measures are required [1]. To this regard, structural performances of constructions, components and equipment are certainly relevant when natural hazards, like earthquake or wind storm, are concerned.

In recent years, Quantitative Risk Analysis (QRA) procedures, originally developed for nuclear power plants, have been extended to other typical industrial installations, i.e. petrochemical, chemical plants or facilities for storage of hazardous materials [2,3]. This circumstance is also related to the emanation of well known Seveso EU directive [4] concerning safety of facilities at relevant risks, that have been strictly classified depending on the type of process and the amount of hazardous material present within the plant. The objectives of (QRA) of industrial facilities is to estimate the consequences derived to the external or internal events; consequences in terms of environment damages, economical loss or also the loss in terms of human life. All risk applications and procedures deal with the occurrence of individual failure events and their possible consequences on the analysed system. However deterministic or a probabilistic approach, or a combination of them can be used, for instance by using cut-off value for consequence-based analysis.

When the seismic – industrial risk is of concern, deterministic approach for the seismic action can be referred to the Maximum Credible Accident analysis or to a Worst Case Analysis, both starting form worst case earthquake scenarios, for the evaluation of risks and consequences. These approaches are used in some European countries within EU regulations for emergency planning outside industrial installation but often lead to large overestimation of the total risks, often providing a risk grade which is both economically and politically not applicable, e.g. in the case of civil protection action. Moreover, the uncertainties on the initial conditions for either the seismic scenario or the evolution of the industrial accident scenario related to the earthquake itself are often too large.

This is the reason why analysts tend to use a probabilistic approach, where uncertainties are explicitly taken into account and described through random variables, by their probability distributions. As a first conclusion, risk assessment tools have then to be developed for both the approaches, taking into consideration the main purposes of risk assessment. It is also worth noting that, with specific reference to earthquakes, very low intensity seismic waves can trigger catastrophic industrial accidents starting from relatively small release of energy (as a jet fire towards toxic of flammable storage tanks), as escalation effects are among the main factor affecting industrial safety. Eventually, either deterministic or probabilistic analyses have to be clearly addressed, since the beginning: human effects, environmental effects, economic effects, or their combination. In this framework, an effort has been devoted to increase the knowledge and to develop simplified “engineering” tools for the analysis of industrial accidental scenarios produced by interaction of earthquakes with industrial equipments containing relevant amounts of hazardous materials, either toxic or flammable or both. To this aim, principal classes of equipment have been sketched. In particular a detailed study on these defined classes of equipment has been conducted to carry out a design and construction standardization in the framework of seismic risk analysis.

2 INDUSTRIAL PLANTS

A large study of typical industrial equipment has been conducted both in terms of industrial process, to know the service condition, and in terms of geometric and structural characteristic. In this section a list of studied structures is reported. The structures and structural details studied are: supports of vertical tanks; reinforced concrete structures for vertical tank support; support for horizontal tanks; anchorages; cathedral furnaces; high pressure stream boiler; fractionating column for hot products; fractionating column for cold products; train of exchangers; atmospheric and pressurized storage tanks; under-ground tanks for GPL; pumps;

compressors.

Figure 1 shows a typical fractionating column that is used in many processes to separate hot product. In such component, usually installed downstream to the cathedral furnaces for thermal cracking (Figure 2), the hot product, in mix phase, is separated by the internal plates of the column. The resulting product (Quench Oil) is sent to the exchanger (Figure 3) to be filtrated. Fractionating column can be atmospheric or low pressure, and can be included in a large class (*atmospheric or low pressure equipment*) which includes a relevant number of operational units as dryers, separators, cyclones, distillation towers, extraction units, low pressure reactors, boilers, heat exchanger, ovens, and furnaces, pumping system, which are characterised by relatively small volumes with respect to the large-scale storage tanks. Hazardous substances can be gas, or dust or liquid, toxic or flammable or both. Risk assessment is specific to the scale of unit, to the operating conditions (high temperature, low temperature), to the presence of one or more physical phases, to the specific auxiliary system installed.

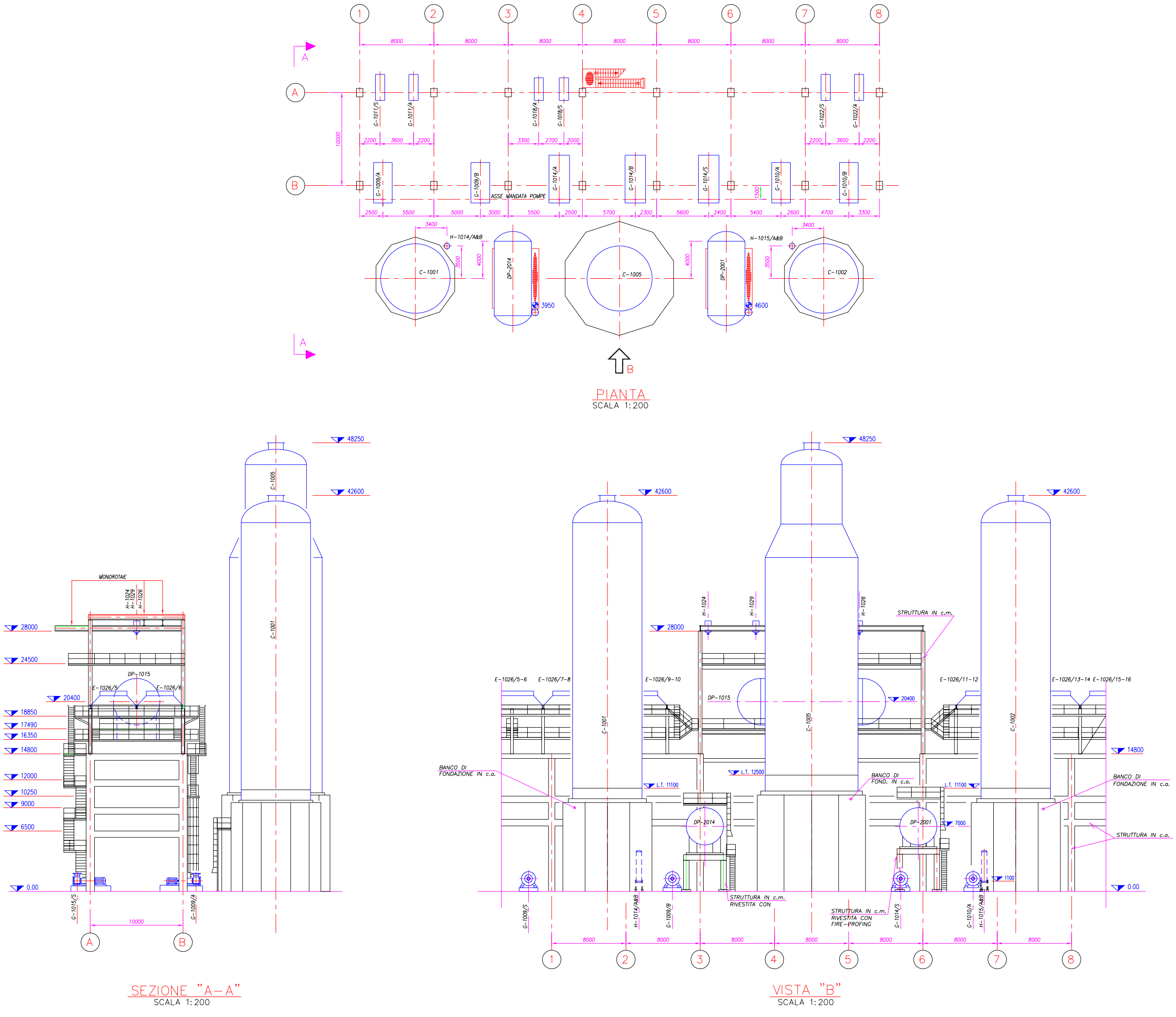


Fig. 1: Example of typical installation of fractionating column for hot product.

Risk assessment is often poorly performed even in the design phase, and QRA often refers to approximate solution starting from the amount and condition (Temperature, Pressure) of substances in the main section. Quite clearly, economical losses can be consistent for the complexity of system but the evaluation is completely separated from QRA. As an example, if earthquake causes loss of control of equipment in a dust drier, an internal explosion can occur, thus destroying the entire equipment and often producing catastrophic escalation of events. This incident is not related in any point with the structural damage of equipment due to seismic load, which can be economically not relevant for the single equipment but in turns has allowed the destructive explosion of equipment (because the varied fluid-dynamic conditions of equipment.

Due to the relatively small amount of hazardous materials, environmental issues are not relevant for this class of equipment unless release of toxic dispersion in the atmosphere is considered. However, this issue is included in QRA. For the entire set of equipment, no reference is given to the risk related to the fire and to the combustion product of substances (often toxic) stored in warehouse (either liquid or solid) and ignited for the escalation of primary accidents triggered by earthquake, as it is out of the scope of this study.

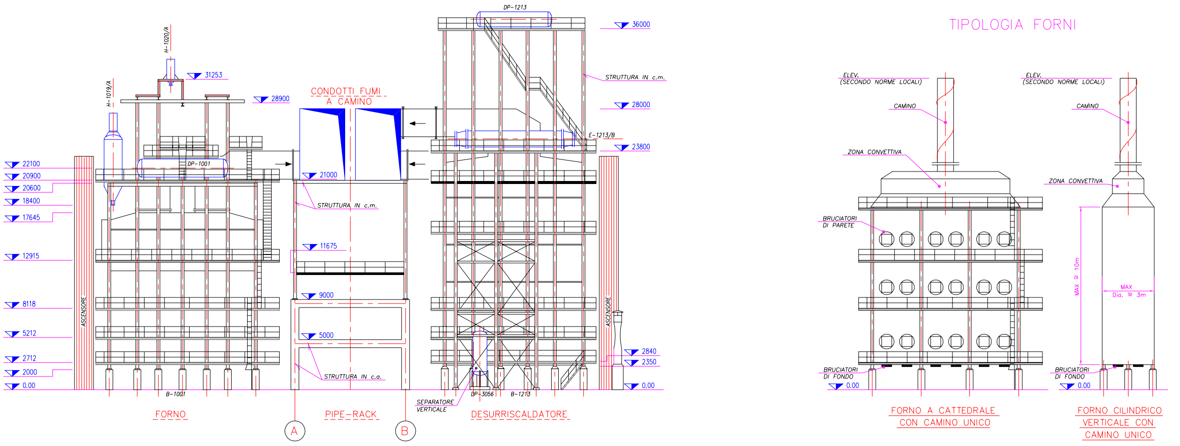


Fig. 2: Example of *cathedral furnaces* used to thermal cracking of liquid or gaseous hydrocarbon as Ethane, Propane, Naphtha, Gas Oil.

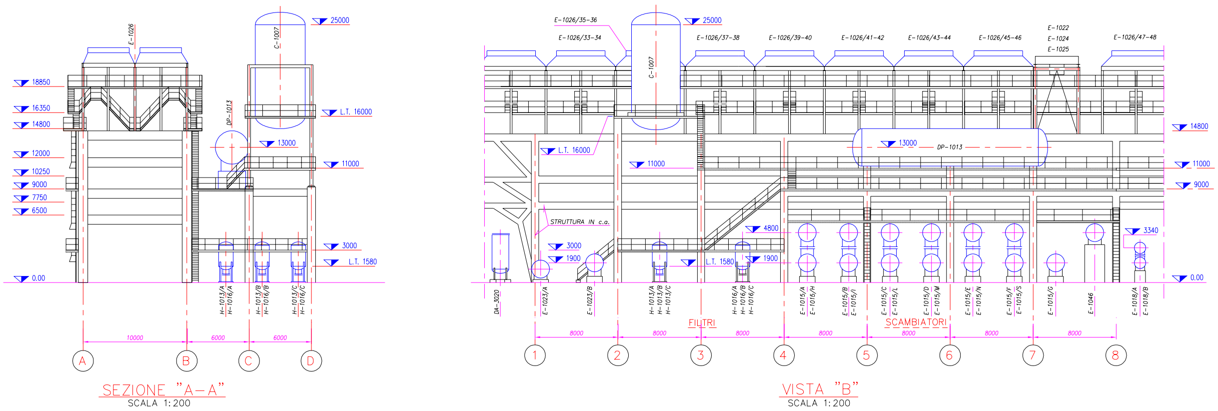


Fig. 3: Example of *train of exchanger* used to cool Quench Oil in industrial process.

The product or the feeding of industrial processes can be stored in *steel tank* (Figure 4), to use it as combustible for furnaces in the example reported above. This type of equipment (*atmospheric liquid fuel storage*) is characterised by the presence of large amount of flammable substance which can be released if seismic wave is able to cause structural damage to the shell or to the auxiliary equipment. Hence, it has to be treated separately with respect to the larger class of equipment described above, due to its importance and diffusion in the industrial facilities. To this regard, as it is mandatory, any hazardous substance storage has to be installed within catch basin whose volume is equivalent to the liquid volume contained in the tank. Moreover, it is good engineering practice to provide several active strategies for prevention and mitigation of accidental releases as foaming, sprinkler, water deluge. The evaluation of risks due to the interaction of earthquake with equipment is mainly related to the evaluation of risks produced by structural damage of tank, which can be in turns the basis for evaluation for the economical losses, provided the cost of damage repairs is given. Environmental issues, provided that atmospheric dispersion of vapour has been previously faced, are only related to the dispersion of liquid in surrounding rivers or see. Risk assessment is then related to the evaluation of probability of occurrence of release in water due to the failure of industrial safety system and mainly to the prediction of the flow rate if multiple tanks are affected by earthquake.

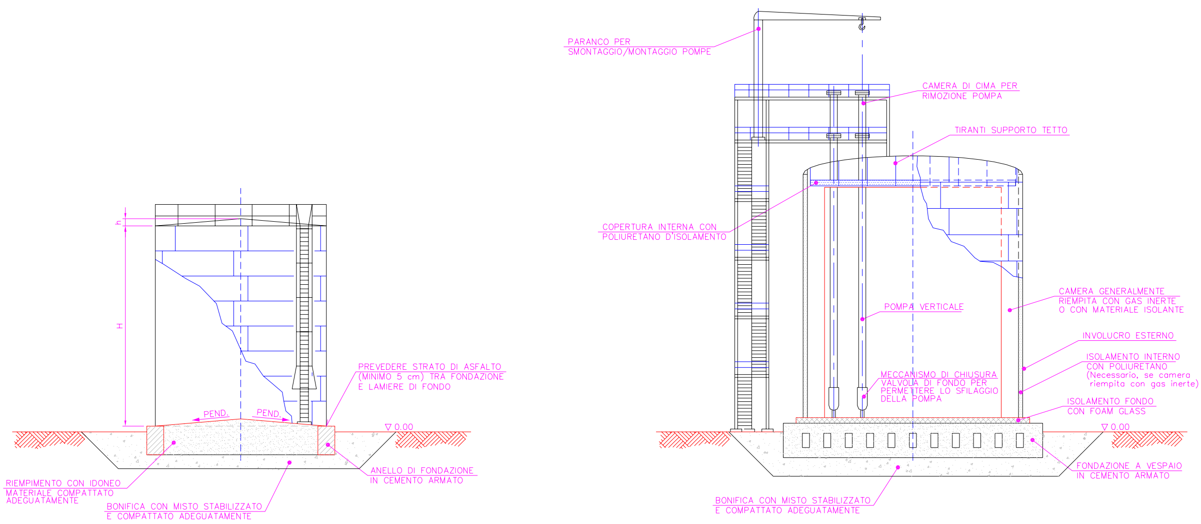


Fig. 4: Example of *Steel Storage Tanks*.

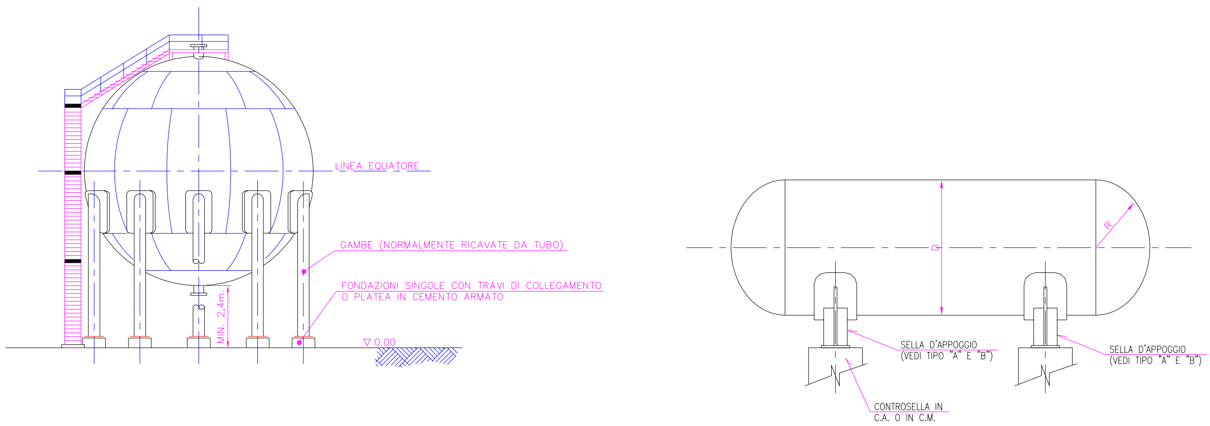


Fig. 5: *Pressurised gas and vapour storage system* (spherical (left) and horizontal (right)).

Other equipment usually present in industrial plants are *above-ground pressurised gas and vapour storage system* (Figure 5). This class of equipment is very common in industry and collects a number of typical units operating either as storage or as operational unit in production processes. The main difference with the atmospheric tank is related to the possibility of large loss of containment even for very small crack or failure produced by earthquake, as the pressure difference with atmosphere is the main driving force. Risk assessment is related to the entire set of accidental scenario which derives from the release of toxic or flammable gas or vapour. As for atmospheric systems, structural damage is the starting point for the evaluation of release and the entire analysis allows the assessment of cost for repairs and restoring the process. Due to the hazard of storage tank or reservoir, it is common use to bury or mound storage tanks (Figure 6) if possible, in order to avoid any escalation effects in the case of fire, and any damage to the shell of equipment (*Under-ground* *gas and vapour reservoir or tank*). Moreover, any release is relatively halted by the presence of soil. Environmental issues are practically absent, unless toxic gases are stored. In this case, however, dispersion analysis, which is necessary for QRA, covers also environmental issues. Economical issues are related to the repairs of system, if affected by earthquake.

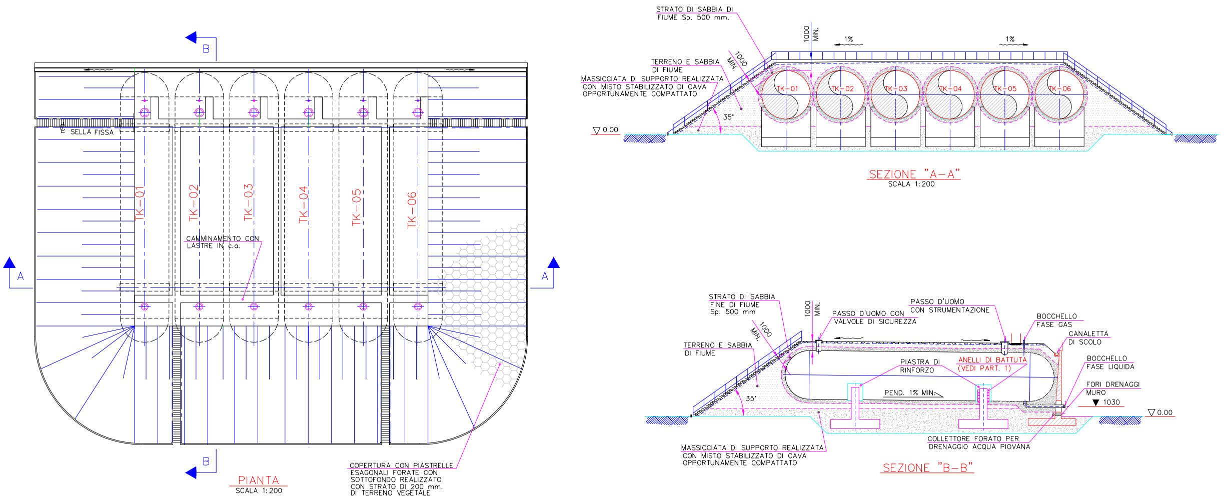


Fig. 6: Example of typical installation to under-ground storage of GPL.

3 STRUCTURAL SYSTEMS

From a structural viewpoint, construction located in a industrial plants depending on their geometrical and structural properties may be divided into two categories: building like structures and non-building like structures.

3.1 Building like Structures

Building structures typically found in an industrial plant include administration buildings, control buildings, substations, warehouses, firehouses, maintenance buildings, and compressor shelters or buildings. They are typically single story buildings, but may have as two or three stories. Lateral force resisting systems used include shear wall, braced frames, rigid frames, and combinations. These are structures such as pipe ways, equipment support frames and box-type heaters which have a lateral force resisting systems similar to those of building systems, such as braced frames, moment resisting frames or shear wall systems. A flexible structure is typically defined as having a natural period of vibration of 0.06 seconds or more, which is equivalent to a frequency of about 17 Hz or less. Examples of building-like structures found in an industrial plant include: moment resisting frames (steel or concrete) or braced frames (cross-braced or chevron-braced) supporting exchangers and horizontal vessels. Such structures can be up four or five levels high; pipe ways with lateral force resisting systems that are moment resisting frames (usually in the transverse direction to provide access beneath the pipe way) or braced frames (usually in the longitudinal direction); rectangular furnaces.

3.2 Non-Building like Structures

Other constructions different respect buildings are typically classified as non-building like structures. This category covers many structures and self supporting equipment items found in a typical industrial plant, such as vertical vessels, horizontal vessels and exchangers, stacks and towers. Non-building-like structures found in an industrial plant fall into four categories: rigid structures, i.e., those whose fundamental structural period is less than 0.06 seconds, such as horizontal vessel or exchanger, supported on short, stiff piers; flat-bottom tanks supported at or below grade. Such structures respond very differently during an earthquake. Special issues for unanchored tanks, such as the effects of fluid sloshing and tank uplifting must also be considered; other non-building-like structures. Example of this category of structures include skirt-supported vertical vessels, spheres on brace legs, horizontal vessels or exchangers on long piers, guyed structures, and cooling towers; combination structures. In petrochemical facilities, such structures generally supported flexible non-structural elements whose combined weight exceeds about 25% of the weight of the structure. A typical example is a tall vertical vessel, furnace or tank supported above grade on a brace or moment resisting frame. The analysis method depends on whether the non-structural element is flexible or rigid, and whether its weight exceeds or is less than about 25% of the weight of the supporting structure.

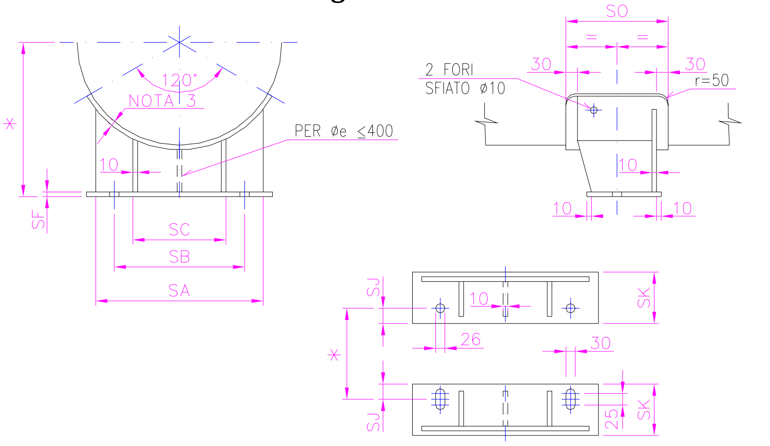
4 STRUCTURAL STANDARDIZATION

The above classification of structures located in industrial plants showed the relevance of steel in many applications, especially when pressurised equipments are concerned. Information reported, however, cannot be directly used in the framework of a seismic risk analysis, since critical data cannot be easily found. This is the reason why an effort has been devoted to collect, standardise and report a number of parameters very useful from a seismic perspective. In particular, steel thickness, properties of materials, connections and masses both at installation and service conditions have been assessed. In the following tables only a reduced number of results can be shown for sake of brevity.

Table 1: Summarizing table for horizontal steel tank.

HORIZONTAL TANK								
TANK DIMENSION			MATERIAL: CARBON STEEL PRESSURE MAX 21,8 bar			MATERIAL: STAINLESS STEEL PRESSURE MAX 19,2 bar		
Volume m^3	Diameter m	Height m	Thickness mm	Weight Kg	Total Weight Kg	Thickness mm	Weight Kg	Total Weight Kg
1	0,8	2,0	5	260	320	4	210	270
2	1,0	2,5	5	410	500	4	330	420
3	1,2	2,5	5	510	620	4	410	520
4	1,2	3,5	5	670	800	5	670	800
5	1,3	3,5	6	880	1060	5	730	910
7,5	1,4	4,5	6	1170	1350	6	1170	1350
10	1,6	4,5	6	1380	1600	6	1380	1600
15	1,8	5,5	6	1850	2130	6	1850	2130
20	2,0	6,0	6	2260	2600	7	2640	2980
25	2,2	6,0	7	2960	3400	7	2960	3400
30	2,4	6,5	7	3500	4030	7	3500	4030
50	2,8	8,0	8	5700	6300	8	5700	6300
80	3,0	11,0	9	9000	9900	8	8000	8900
100	3,2	12,0	10	11200	12300	8	9300	10400

Table 2: Summarizing table and structural details for support of horizontal steel tank.



øe RECIPIENTE	SA	SB	SC	SF	SJ	SK	SO
≤ 250	180	120	–	10	50	120	180
251 ÷ 300	200	140	–				
301 ÷ 350	250	190	–				
351 ÷ 400	270	210	–	13	55	140	210
401 ÷ 450	310	230	130				
451 ÷ 500	350	270	170				
501 ÷ 550	370	290	190		65	170	250
551 ÷ 600	400	320	220				
601 ÷ 650	470	390	290	16	80	200	280
651 ÷ 700	510	430	330				
701 ÷ 750	550	470	370				
751 ÷ 800	570	490	390				
801 ÷ 850	600	520	420				
851 ÷ 900	640	560	460				
901 ÷ 950	680	600	500				
951 ÷ 1000	710	630	530				
1001 ÷ 1050	750	670	570				

Table 3: Heat exchangers table and structural details.

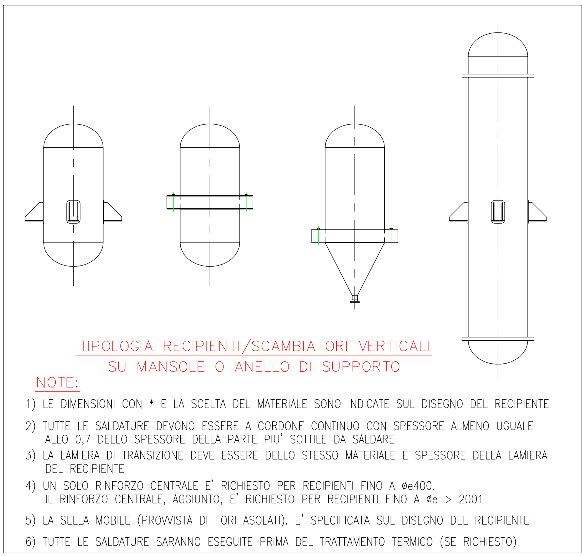


TABELLA DIMENSIONI RECIPIENTI VERTICALI STANDARD CON FONDI ELLITTICI

DIMENSIONI RECIPIENTE			MATERIALE ACCIAIO AL CARBONIO CON PROVA IDRAUL. MAX 21,8 bar			MATERIALE ACCIAIO INOX CON PROVA IDRAUL. MAX 19,2 bar		
Capacità m^3	Diam. Int. m	Alt. T.L. m	Spess. Mant. mm	Peso (1) Kg	Peso tot. (2) Kg	Spess. Mant. mm	Peso (1) Kg	Peso tot. (2) Kg
1	0,9	1,5	5	240	280	4	190	240
2	1,1	2,0	5	390	460	4	310	380
3	1,2	2,5	6	610	710	4	410	520
4	1,3	3,0	6	770	900	5	640	770
5	1,4	3,0	6	850	990	5	700	850
7,5	1,6	3,5	6	1120	1260	5	940	1080
10	1,8	3,5	6	1300	1460	5	1100	1270
15	2,0	4,5	6	1800	2010	5	1500	1720
20	2,2	5,0	7	2560	2870	6	2190	2410
25	2,4	5,0	7	2860	3200	6	2450	2800
30	2,6	5,5	7	3380	3780	6	2900	3310
50	3,0	6,5	8	5240	5610	7	4590	4970
80	3,2	9,0	8	7200	7690	7	6300	6800
100	3,2	11,5	8	8800	9400	7	7700	8350

5 CONCLUSIONS

This paper reports some results of an investigation devoted to assess the risks of typical equipment installed in industrial plants when subjected to seismic loading. The main objective is the definition of a clear classification of constructions from the structural engineering perspective. The study represents a useful support for QRA analysts in seismic areas, because it ensures a simulated design of constructions and processes even when data are not available. Standardisation of details, supports, anchorages and structural solutions, has been reached and a number of design tables has been issued covering critical equipments.

ACKNOWLEDGMENTS

This study has been conducted in within the activities of the LESSLOSS project subtask 2.3b (www.lessloss.org), a research endeavour funded by the European Commission within the scope of FP6, the Sixth European Community Framework Programme for Research, Technological Development and Demonstration.

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KEYWORDS

Industrial plants, steel components and systems, seismic risk, industrial process.