ASEISMIC DESIGN OF AN OIL REFINERY IN THE STATE OF ASSAM - INDIA

Alexandru Cişmigiu [x] Emilian Tiţaru [xx]

Note:

During 1959 the authors have collaborated in drawing up an aseismic structure for an Oil Refinery, supplied by the Roumanian Government and located in the State of Assam-India. Some specific aspects in the achievement of an aseismic protection are described below:

1. SEISMIC STRUCTURE OF THE STATE OF ASSAM

The State of Assam is known to belong to a zone of earthquakes of considerable strength, situated along the rugged arches of the Himalayas and Burma, being the most active seismic sector of the alpide belt.

The site of the refinery was established near the ridge of the Shillong plateau (near the Brahmaputra river) in the epicentric zone, where the big Indian earthquake of June 12, 1897 occured. This earthquake has been considered as one of the most powerful in history; it was felt over more than 4 million square kilometers and on 75.000 square kilometers all stone constructions were destroyed.

In the epicentric zone the amplitude reached 3o cm. and land settlings reached 12 meters; 5ooo aftershocks having occured within the next 1o years.

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x Alexandru Cismigiu, Chief Design Engineer, I.P.B. Design Office for the City of Bucharest, Address: Dionisie Lupu, 4

xx Emilian Tiţaru, Chief Design Engineer, IPCMC, Design Office for Structural Engineering, Bucharest.

2. FORMS OF STRUCTURES TYPICAL TO REFINERIES.

In refineries the following forms of specific structures may be distinguished: distillation columns, oil tanks, horizontal vessels chimney stacks supported by abutments, technological platforms with one or two levels, steam boilers, tubular ovens, thermo-electrical plants, pipe-line systems, sewerage and water supply systems.

The structural and dynamic features of these constructions differ very much, therefore the aseismic solution was examined from case to case.

3. CHARACTERISTICS OF THE SOIL-FOUNDATION SYSTEMS

In general the soil may be considered as medium - firm ground. In certain zones lenses of soft-slimy layers may be found; the first thin layers appear at the depth of 4 to 5 meters, and the second one below 15 meters, in thickness up to 1o meters. The following foundation systems have been adopted from case to case: direct foundation or foundations on piles.

4. DETERMINATION OF SEISMIC FORCES

For the determination of seismic forces we received from the Indian refineries the spectrum shown in figure 1. The seismic base shear is determined by eq. (1):

$$Q_B = c.P$$

in which "c" is taken from diagram (as shown in figure 1a.) The distribution of seismic forces along the height is given by eq. (2):

$$S_i = Q_B \cdot \frac{P_i \cdot h_i}{\sum P_i \cdot h_i} \quad (2)$$

Analysis and conformation were carried out in accordance to the Roumanian Specifications (1). The form of this spectrum was identified by the authors to be approximately identical to the medium forms of the acceleration spectra of Californian earthquakes (2). The damping factor "n" has been identified to be about 5% of n_{cr}, corresponding to steel structures. Regarding the use of the this spectrum for structures with several degrees of freedom,it is probable that an equivalence was made for these structures with a one-mass systemusing an average factor of o,6...o,7. The seismic intensity was considered to correspond to great magnitudes 7-8 at. 5o or more miles from the epicenter.

Compared with Roumanian Specifications the following differences arise: (FIG. 1B)

1) The unique force factor "c" does not allow for the differentiation of forces with respect to variations of the damping factor.

2) For the structural forms typical for refineries, the equivalence factor has resulted from calculations to be o,5 - 1,o for the first mode, thus showing important differences as compared with the medium value taken into consideration.

3) Eq. (2) of distribution is valid only for a linear elastic line of mode 1.

4) The influences of higher modes cannot be solved because the corresponding formulas for the equivalence factor and for the distribution of seismic forces, valid for any mode, are missing.

The Roumanian Specification equations, of a general character, entirely allow for the various particularity of the structures of a refinery: (FIG. 1B)

$$Q_B = \alpha . \psi . \varepsilon . P \; ; \; \psi = \frac{2.92}{\sqrt[3]{n}} \; ; \; \varepsilon = \frac{[\Sigma P_i . u_i]^2}{[\Sigma P_i][\Sigma P_i . u_i^2]}$$

in which:

α = spectral factor established for n = o,2o n_{cr}.
ψ = function of damping
ε = equivalence factor
Q_B = base shear

We mention that for extremely rigid structures ($0 < T < 0{,}1$ sec) with practically no damping, the value of factor C should be increased two or three times.

5. ASEISMIC PROTECTION MEASURES.

5.1. OIL TANKS .

- The volumes of tanks are in the range of 2ooo to 5ooo tons. (FIG.2)

– The solution of fixed covers was adopted, as this type is less exposed to damage, due to seismic vibrations of the liquid in form of "waves". Measures have been taken to protect the cover against the "seismic wave" acting in an upward motion, by reinforcing the trusses, by providing additional bracings, by fixing the sheet-iron to resist tear and by reinforcing the top outlining ring. The seismic wave action was estimated assuming the liquid surface inclined by 15%. According to the Roumanian Specifications, the distribution of the seismic pressures in a horizontal plane is uneven (see fig.3).

To ensure resistance of the walls against ovalization effects, 2-3 horizontal rigidity rings have been foreseen.

To solve the supporting details of the tank, constructive measures have been taken to prevent the lifting of the sand from below the outlining ring owing to the effect of complex vibrations of the tank, by introducing a concrete belt under it. (See fig.4). Likewise, the basic ring of the tank has been locally strengthened as compared with current solutions (by welding vertical steel corners to it, by thickening the marginal bottom sheet iron, and by introducing a bracket of 100 mm). It is recommended to build the jointing of the tank with the filling and emptying pipes by means of flexible connections.

5.2. DISTILLATION COLUMNS

– The principal types of columns are shown in figure 5.

In determining vibration shapes and periods, besides the flexural deflections of the column, deflections of the supporting frames, as well as rotations due to soil settlements were considered from case to case.

In the case of foundations on piles, the rotation of the foundation was neglected.

Calculus of the periods, forms of vibration and of forces have been made by means of methods developped in paper (1). For this type of structure, the flexibilisation of the lower part (see type 2) due to its support frame and taking into account the rotation of the foundation leads generally to a decrease by 5o% of seismic forces.

It is to be mentioned that in a correct analysis (1) when the rotation of the foundation is taken into account, the foundation mass must be included in the force P and in the distribution of Si forces.

It is therefore advisable that foundations should be as light as possible, stable and should permit rotations.

The enchasing of the column with the ground can reduce appreciably the vibration period (up to o,2 sec.) For type (3), where for technological reasons 2 columns of over 5oo tons each and two light towers of 55 m. height were grouped on the same foundation mat, each structure was analysed as fixed in the foundation plate.

For light and flexible metal towers, the computed seismic forces have resulted smaller than those produced by wind load.

On the contrary, for columns the bending moment resulting from seismic forces exceeded 25oo tm. Considering working conditions as well as vibration differences, the seismic forces for the design of the foundation plate have been established as follows:

for column Nr.1... 1oo%, for column nr. 2... 25% and for towers ...5o%.

For type 4 we considered that both columns do vibrate in the same phase.

- To ensure resistance, in some cases, the column mantle has been thickened, whereas rigidity rings were provided to prevent buckling.

- For fixing columns into the socle special attention has been given to anchorage bolts. High quality steel was used capable of big plastic strain. We preferred small diameter anchorage bolts places at smaller intervals. It was appreciated that by these measures the dynamic adaptation of anchorages could be increased. It is desirable that constructive solutions be adopted which allow the probable replacement of anchorage bolta, if big plastic strain occurs. Likewise when designing bolts for the creation of strength reserves, an increase of the seismic stress has been allotted to the supporting shoes for fixing bolts and the basic ring has been strenghthened accordingly.

5.3. HORIZONTAL VESSELS

The usual types are shown in fig. 6.

Horizontal vessels are characterized in general by a very rigid structure and, in case the foundations are of greater depth, the period can be lowered under o,1 sec. For these structures account must be taken of thermal stress. Maximum forces up to 100% of gravity have been prescribed, acting along any direction in space.

The vessels were tied to the foundations in order to ensure resistance to seismic forces. Fixed supports prevent displacements in every direction. Mobile supports allow the displacement due to thermal variations only alongside the vessel, but prevent the tearing away of the vessel from its supports under earthquake action.

- By tying the foundation legs together by means of strong girders, the longitudinal seismic forces acting on the fixed support are shared by all foundation legs.

- For mobile supports special anchoring devices have been designed.

5.4. PLATFORMS FOR SUSTENSION OF VESSELS

These platforms may have one or more storeys (see fig. 7) and are designed usually as structures in reinforced concrete flexible frames. The analysis of the frames has no special features.

The equivalence factor varies form o,85 to 1,oo. The anchorage of vessels placed on platforms has been designed to resist forces equal to 1oo% of gravity.

5.5. CHIMNEY STACKS.

- The chimney of the tubular oven is 5o m. high, and is built in steel.

- The influence of vibrations of higher modes was also considered in the determination of seismic forces.

Analysis results have shown that due to reduced mass and to flexibility, the wind stresses were predominant.

5.6. TUBULAR OVEN

In the design of the tubular oven (see fig.8) both seismic forces and thermal effects were taken into account. Transversely, the structure is composed of flexible steel frames. In the longitudinal direction the structure is rigid, because the pillars are braced by means of beams with bolted steel plates.

The roof is braced by trusses and forms a rigid diaphragm.

The rigid gables are separated from the building and are anchored at the roof level with connections in the form of pendulums. This was necessary for two reasons. In the first place to ensure free displacements due to thermal effects. In the second place, the tying of the main structure would have increased the transverse rigidity, consequently also the seismic forces.

As the gables are much more rigid than the frames, this would mean that the seismic forces should have been resisted to only by the gables, which however, would not have enough strength.

At the interior of the steel frame work a thermic insulating layer exists, consisting of refractary brickwork both on the ceiling as well as on the walls.

The refractary brickwork on the ceiling has been suspended by special devices and is lightly braced. The brickwork is anchored to the coating by special joints. The whole refractary brickwork is composed of blocks of special form, each one anchored separately, so that the effect of seismic forces should be resisted to only by the steel frame. Thus the refractary brickwork has been solved as a nonstructural element.

5.7. STEAM BOILER

The construction of the steam boiler is composed of three important parts: the inner steel frame, the refractary brickwork, and the pressure equipment.

For this construction the thermal effects were considered too.

The steel coating which is nonseismic zones is composed only of a simple system of columns and beams, was designed in that case as a system of frames with rigid joints.

To the frame bars the steel suspension plates of the refractary masonry work are attached with bolts.

The upper floor has been solved as a rigid horizontal disk (consisting of sheet iron and beams welded together) so as to ensure spatial cooperation of the system of frames with diaphragms.

With regard to masonry, this has been solved in the same manner as for the tubular oven (5.6.)

The pressurised equipment at the interior of the tank has been fixed to the main construction, so that their thermal expansion should be free, but their rocking be prevented under earthquake action.

5.8. PIPELINE SYSTEM FOR OIL AND REFINING PRODUCTS

The following principal measures were recommended:

1. Weldings should be done according to special working specifications in order to reduce and eliminate initial internal stresses and to prevent diminution of the plastic properties.

2. In general, cast iron fittings should be avoided.

3. Expansion pipes should be provided in a sufficient number in order to avoid buckling and tear by telescopic compression.

4. In the support zones of pipe packages, free displacement should be ensured from case to case; at the same time their rising from the supports should be prevented.

5.9. SEWERAGE AND WATER SUPPLY SYSTEMS

The recommended measures were:

1. The connections with buildings and equipment should be made by means of flexible elements, and the passage through foundations of buildings should be free.

2. For pressure pipes, expansion joints should be foreseen.

3. Connections to concrete pipes should be of semi-flexible type.

4. Distances between visiting chambers should be nearer than in non-seismic zones.

5. Steel pipes should be supported only by very

compact fillings.

5.1o. FIRE PROTECTION MEASURES

Additional measures required in the event of seismic damage causing fire, were considered in addition to normal fire protection measures.

CONCLUSIONS

The experience in designing this Refinery has pointed out that a correct aseismic design should not be limited to the determination of conventional seismic forces isolated from the specific of structural problems and from its mode of construction. A complete aseismic project must be based on the dynamic analysis methods of forces and structures, taking into account all dynamic and constructive properties of typical structures and on a special aseismic conformation followed in every detail.

The aseismic project must take care not only of the design of usual buildings, but it must take into account also the problems of special structures for industrial equipment, for which documentation sources are for the time being very scarce.

It is known that damage of equipment may result in appreciable losses by stopping production.

Although the problems of aseismic design are very complex and scientifically still present many unsolved aspects it is nevertheless possible today to give a complete engineering answer to the practical solution of the most intricate structures and equipment.

N O T E

1. From the technological and aseismic points of view the Refinery project has been entirely worked out by the Design Bureau for Oil Industry in Ploesti Rumania.

2. The measures foreseen for this refinery were

applied also to other structures in the oil industry situated in Roumania or in other countries.

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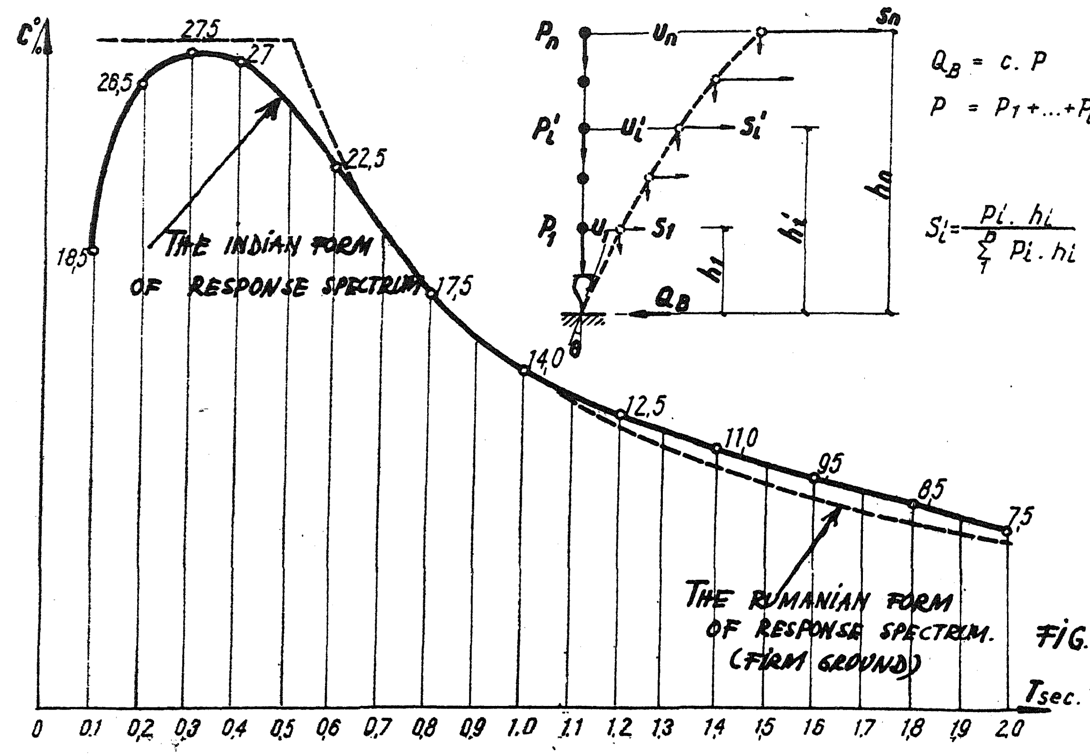

Fig. 1.a. The response spectrum from the Indian Refineries

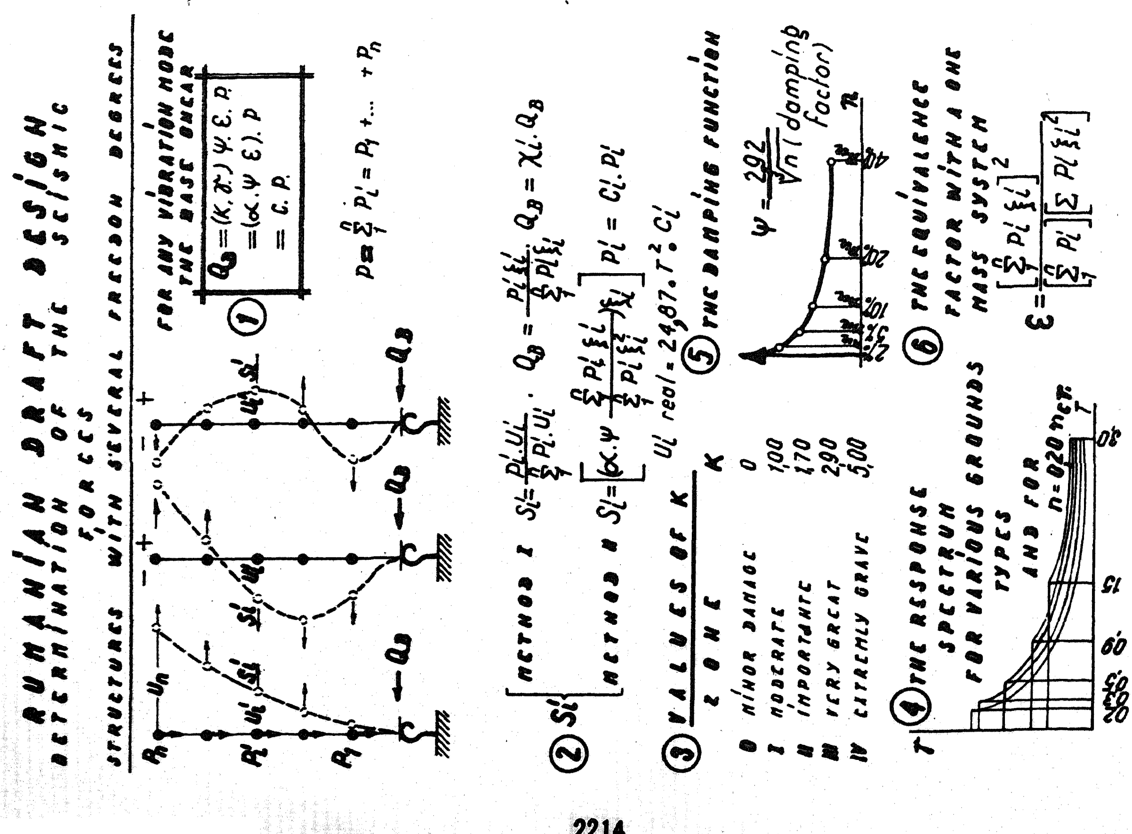

Fig. 1.b. Rumanian draft design. Determination of the seismic forces

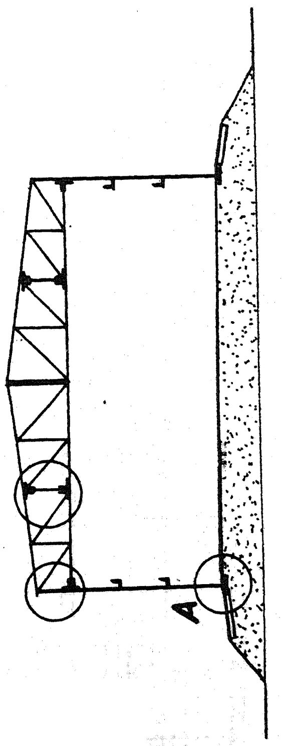

Fig. 2. Oil tanks

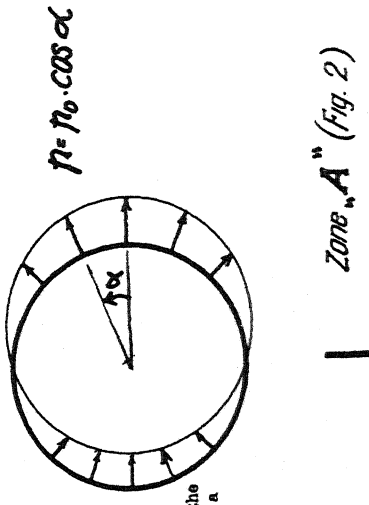

Fig. 3.
The distribution of the seismic pressures in a horizontal plane for tanks.

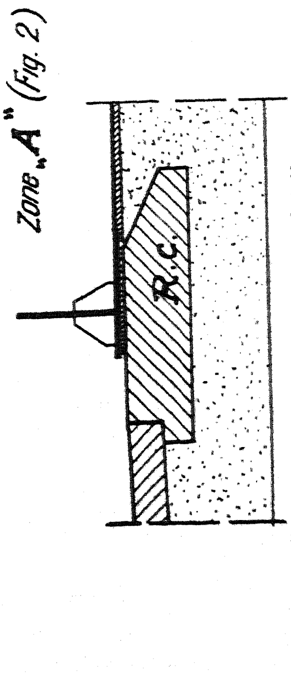

Fig. 4. The base ring. Detail.

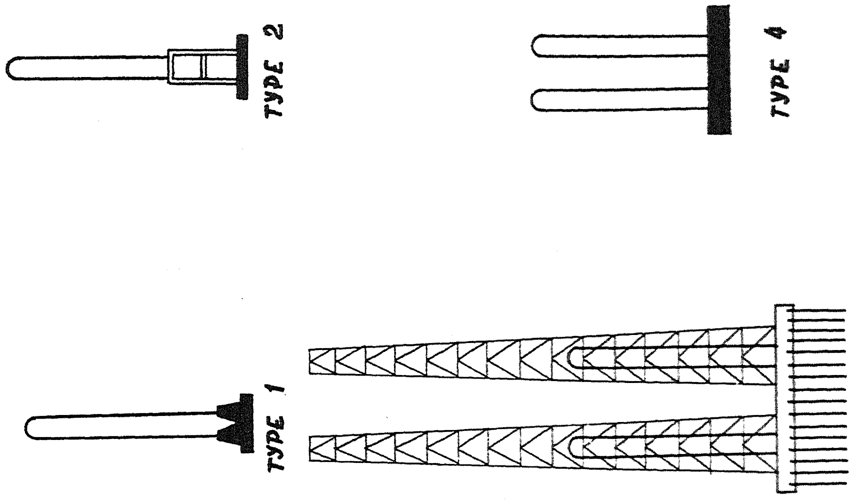

Fig. 5. Distillation columns.

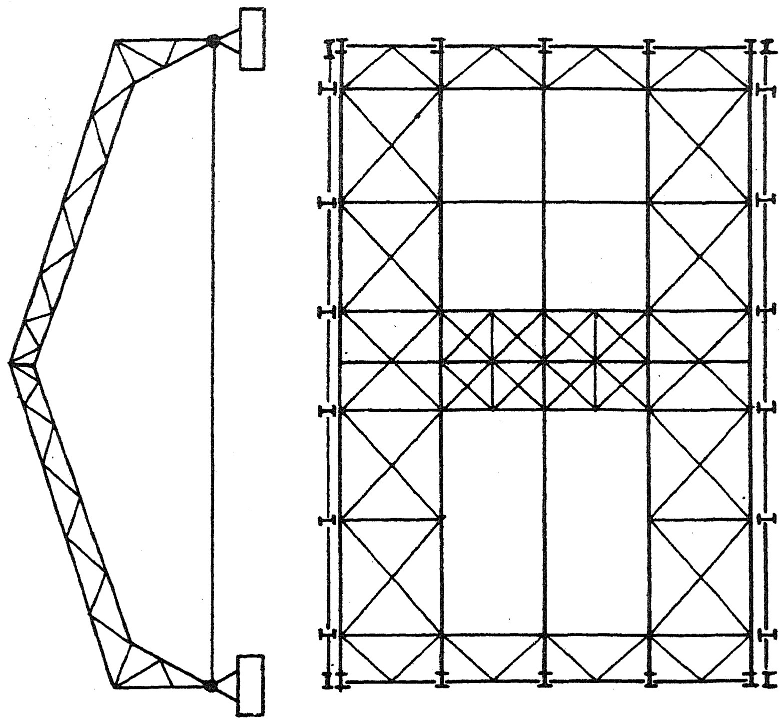

Fig. 8. The tubular oven

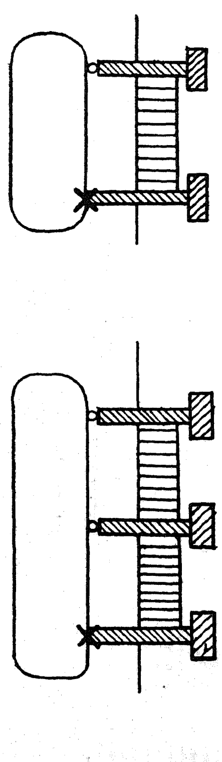

Fig. 6. Horizontal vessels

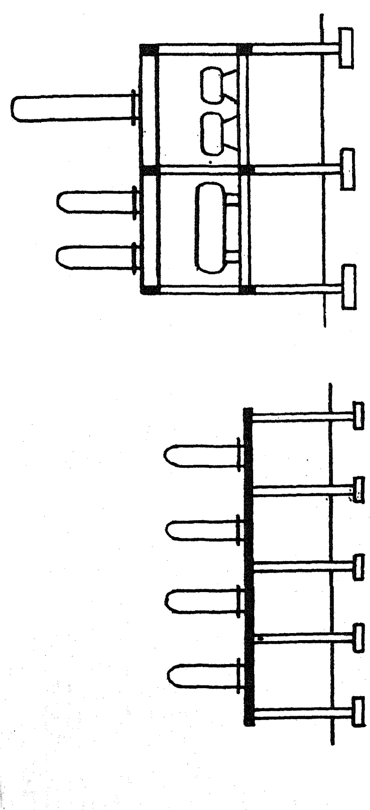

Fig. 7. Platforms for sustension of vessels