Silos and tanks

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EC 1: Silos and Tanks

EC 1: Silos et réservoirs

EC 1: Silos und Behälter

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SUMMARY

The paper briefly describes the background to the preparation to the part of the Eurocode on Actions in Silos and Tanks. The work of the ISO/TC98/SC3/WG5 formed the starting point for the Eurocode. The paper summarizes the background for the development of the code, its limitations, and progress to date. The plans for completing the work are also described.

RESUME

L'article traite brièvement des bases pour la préparation de la partie de l'Eurocode 1 traitant des actions sur les silos et réservoirs. Le travail du comité ISO/TC98/SC3/WG5 est à la base de cet Eurocode. L'article résume les éléments essentiels ayant servi à l'établisement de cette norme, présente ses limites, ainsi que les progrès réalisés à ce jour. L'évolution, nécessaire à l'établissement définitif de ce projet est également présenté.

ZUSAMMENFASSUNG

Der Beitrag beschreibt den Hintergrund der vorbereitenden Arbeiten am Teil des EC 1 über Einwirkungen auf Silos und Behälter. Ausgangspunkt waren die Ergebnisse der Arbeitsgruppe 5 vom Subcommittee 3 des ISO-Kommittees 98. Es wird einen Überblick über die Entwicklung der Norm, ihre Beschränkungen, den Arbeitsfortschritt und geplanten Abschluss geben.

1. INTRODUCTION

1.1 Scope

The part of Eurocode 1 which deals with actions in silos and tanks will contain recommended methods for determining the actions that arise from the storage of bulk materials and liquids. Reference is also given to actions from gravity, snow, wind, earthquake, temperature and differential settlements as well as accidental actions from fire and explosions.

The calculated actions are for use in designing silos and tanks and their components. However, the field of application is subject to a series of limitations, which means that the structures to be covered can be characterized by:

- Silos with a limited eccentricity of inlet and outlet, with small inertia effects (impact) associated with filling, and with discharge devices that do not cause shock or eccentricities beyond the prescribed limitations.
- Silos containing particulate materials which are free-flowing and have a low cohesion.
- Tanks with liquids stored at normal atmospheric pressure.

1.2 Background

The work was initiated by the Commission of the European Communities. The first step was to collect information on codes and recommendations for loads in silos and tanks. The study was mainly concentrated on EEC member states and reported in 1987 [1]. It was concluded that the work initiated by ISO in ISO/TC98/SC3/WG5 "Loads from Bulk Materials" should be used. When the Eurocode work was transferred to CEN the ISO group had almost finished its work and a draft from June 1990 was accepted as the starting point for the CEN work [2].

Following the CEN procedure a Project Team, PT8, was formed. PT8 has experts from Denmark, France, Germany, Great Britain, and Greece.

The June 1990 draft [2] was circulated for informal comments from national contacts and from national standards organizations. The comments have been evaluated by the Project Team and several changes have been introduced. At the same time an attempt to transform the document to the Eurocode format has been made. The latest draft [3] dated February 1992 thus deviates considerably from the previous draft, and it has been circulated for informal comments during Spring 1992.

2. PARTICULATE MATERIALS AND STORAGE LOADS IN GENERAL

2.1 Material behaviour

To understand the distribution of loads in silos it is important to be aware of a few facts about the behaviour of particulate materials: If the material is compacted by a vertical compressive stress, σ, the response will be a lateral pressure, $\lambda\sigma$, where λ is less than 1 (Fig. 1a). Further, if you slide a portion of the particulate material along the wall, friction stresses will act against the movement controlled by a coefficient of friction, μ (Fig. 1b).

2.2 Storage loads

The following behaviour occurs during filling of the silo: At a given point, the vertical stress increases when more material is placed at the top surface. The vertical stress evidently depends on the bulk weight density, γ. As the vertical stress increases ,both the horizontal stress and the friction against the wall also rise, as explained above. If the silo is tall, the situation may develop in which the wall friction stresses between two horizontal sections almost counterbalances the weight of the material between the sections. When this happens, almost none of the weight of the material between these sections is borne by the material beneath it, so the vertical stress does not continue to rise when further filling occurs. Thus, the vertical stress, and the consequent horizontal pressure against the wall, approach asymptotic values with depth (Fig. 2a). This pressure pattern is very different from the well known hydrostatic pressure distribution found in tanks (Fig. 2b).

The main differences between the two distributions may be evaluated by assuming that two identical containers are filled with materials of equal density: one is filled with a particulate material and the other with a liquid. The pressure distributions will be as seen in Fig. 2a and Fig. 2b. At the top the pressure increases faster with depth in the tank since the pressure in the silo is multiplied by λ, which is smaller than one - typically about 0.5. Lower in the silo, the friction forces make the silo load even smaller compared to the hydrostatic pressure, making the silo load much more favourable for the structure than the hydrostatic load.

Unfortunately, for silos the picture is not quite so simple. A particulate material under compression acquires a certain strength, which means that several pressure distributions are possible depending on different circumstances.

The most important event is the gravity discharge of the particulate solid (Fig. 3). During discharge the particulate material must reach plastic stress states to be able to deform sufficiently to move through the outlet. The pressure near the outlet tends to zero, but equilibrium of the entire mass must be maintained, so pressures tend to increase elsewhere. As a result, a very different pressure distribution may be found during discharge. This change is particularly important in eccentrically discharging silos, where the pressure distribution may become very unfavorable for the structure.

Even with central discharge the pressure distribution may not be symmetrical because the rupture pattern in the solid may develop slightly unsymmetrically or because eccentric filling or irregularities in the wall may cause an asymmetrical distribution. Some of these factors may be controlled by the designer, but others cannot, which means that a symmetrical pressure distribution cannot be expected in practice.

It is important to stress that in silos containing strong particulate materials (small λ's), the magnitude of pressure changes from filling to discharge may be bigger than for weaker materials. A liquid may be seen as an extremely weak material; zero shear strength and thus no deviation from the hydrostatic (filling) pressure distribution.

2.3 Load models

The ISO Committee decided to base the load model on the classical Janssen theory being prescribed for filling. The deviations during discharge are taken into account by empirical factors. It has been questioned if it would not be better to base the code on one of the many newer theories that have been developed. The arguments for retaining Janssens theory for filling are mainly the following:
- it is simple
- it can be used for a wide range of shapes of silo cross-section
- it has been found to be fairly accurate for filling

The arguments to cover discharge and special cases by empirical parameters have been:
- it is simple
- sufficient consistency has not been demonstrated between experimental observations and theoretical predictions to justify a more complicated load specifications, though it is recognised

that such calculations may be useful in certain cases.

2.4 Material parameters

The ISO Committee decided to introduce an interval in the specification of values for the material parameters reflecting the scatter found in practice due to differences in production processes for the materials to be stored, different treatment of the interior surface of the silo, ageing, polishing, etc.

The literature shows a very wide range of values for the same parameters reflecting not only the scatter described above but also reflecting the fact that these parameters are not true material constants, and that they have been determined under a wide variety of different test conditions.

Parameters like γ, λ, and μ are also determined in the fields of soil mechanics and powder technology. It has been natural to adopt the test methods from these areas, but to specify special test conditions which are intended to produce values which are relevant for loads in silos.

One of the questions has been the determination of λ (which is used for filling) from the internal angle of friction, φ, knowing that in principle λ depends on the wall friction. For pressures against a stiff wall two equations for λ are widely accepted to be fairly accurate. One, $\lambda = 1\text{-}\sin\varphi$, is approximately valid for a completely smooth wall. The other, $\lambda = (1\text{-}\sin\varphi^2)/(1+\sin\varphi^2)$, is valid for a completely rough wall. The ratio between the λ's calculated from these formulas is about 1.2 for the range of φ which covers most stored materials. This means that the wall friction angle only influences the value of λ by about 20 per cent. A value of $\lambda = 1.1(1\text{-}\sin\varphi)$ has been introduced as a simple and fairly accurate rule.

Another discussion concerns the relation between the parameters λ or φ and μ. If the wall is rough, sliding down the wall takes place in the form of internal rupture in the particulate material, mainly controlled by φ, so that the parameters μ and φ are strongly correlated. In the case of a smooth wall, sliding does not mobilize the strength of the material and the parameters are independent. For simplicity the parameters are taken to be always independent, which is thus not always correct.

3. CONTENT OF THE DRAFT CODE

3.1 Storage Loads in Silos

Rules are given for tall silos, squat silos, and homogenizing silos.

Tall silos are calculated for loads as indicated in Fig. 4. All loads are treated as variable.

For the filling condition, the horizontal wall load, hopper load, and wall friction load are each calculated from silo geometry and the parameters described above. For different designs, one, two or all three of these three load sets may be controlling. For each of these loads, the most adverse value of the load occurs when a different set of extreme values is chosen for the parameters λ and μ. Thus the horizontal wall load is at its most adverse value when λ is at its maximum and μ at its minimum. One combination of values may control the horizontal reinforcement in a concrete silo, whilst another may control the buckling of a steel silo. Thus the complete design must examine both minimum and maximum values for both λ and μ.

The above loads are all fixed symmetrical loads, but the incidence of unsymmetrical loading on silos is so high that some means of guaranteeing strength under unsymmetrical loads must be ensured. To this end, a notional 'patch load' is added to the symmetrical loads. The patch load is

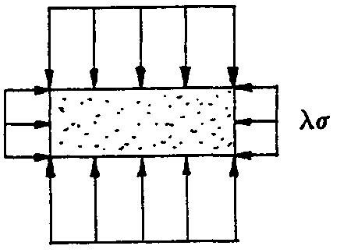

Figure 1a: Relation between vertical and horizontal stresses in a silo

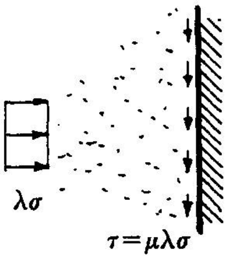

Figure 1b: Relation between horizontal stress and wall friction stress

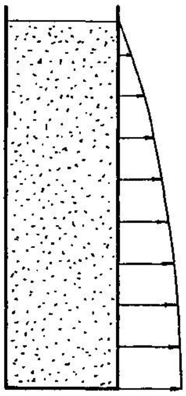

Figure 2a: Horizontal pressure distribution in a silo

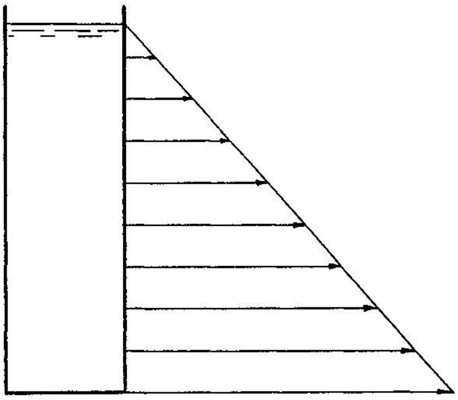

Figure 2b: Horizontal pressure distribution in a tank

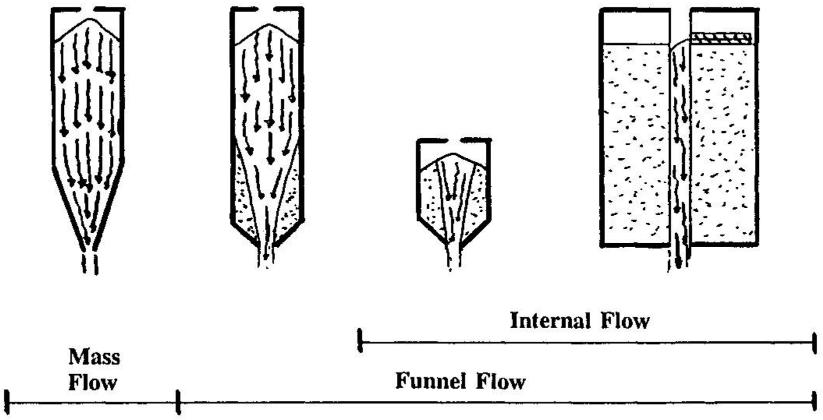

Figure 3: Flow patterns

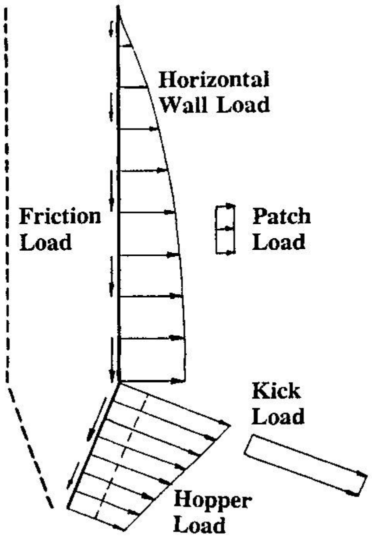

Figure 4: Loads in a tall silo

a live load that acts on any part of the silo wall on two opposite square areas. The magnitude of the patch pressure increases as the eccentricity of the inlet or outlet increases.

The discharge loads on the vertical wall are in the same pattern as the filling loads, but increased by an over-pressure coefficient C, which takes values between 1.0 and about 1.5. The value of 1.0 is for top unloaded silos (no gravity discharge) and for squat silos with height to diameter ratios below 1. The type of material also influences C, so that the materials that are most likely to produce big discharge pressures have higher values of C. The loads on silo bottoms are defined as being the same for discharge as for filling, except that a 'kick load' is prescribed for the upper part of the hopper in mass flow silos.

Squat silos (height to diameter ratio less than 1) are essentially calculated for the filling pressure, with two additional rules. One allows for a more realistic pressure distribution on the upper part of the silo wall. The other prescribes a more realistic distribution of the bottom load, limiting it to a maximum of the density times the distance to the surface.

Homogenizing silos and silos with high filling velocity must be calculated as for other silos but with an additional loading case: a hydrostatic pressure distribution with an aerated density of 80 per cent of the bulk density.

The parameters to be used in all the above calculations may be taken from a table included in the code or may be determined according to specifications given in the code and guidelines given in an annex.

3.2 Storage Loads in Tanks

Tanks are simply calculated for the hydrostatic pressure.

3.3 Other Actions on Silos and Tanks

References are given to other parts of the Eurocode concerning gravity loads, snow loads, wind loads, thermal actions, differential settlements, and accidental actions. However, some information of special relevance for silos and tanks is included. This consist of some guidance related to filling with hot stored materials and some rules concerning pressure distributions for seismic actions to be used together with the Eurocode on seismic loads.

3.4 Combination values

Noticing that silos and tanks are often filled most of the time and that the loads are likely to be present at a high value it is recommended that the load factor as an accompanying action shall be 0.9 times the load factor as a predominant load. The same value is proposed for serviceability limit states. For combinations with accidental actions, 90 per cent of the load should be prescribed.

4 REMAINING TASKS AND TIME SCHEDULE

Especially the following items need more consideration:
- the values of the material parameters given in the draft, and
- the relation between the part on silos and tanks and the other parts of the Eurocodes. The present draft should be seen as only the starting point for the linkage to the other parts of which the most important in this respect are the other parts of EC1, the code for soil mechanics, the seismic code, and the structural codes for concrete and steel.

The remaining tasks and changes as a result of the ongoing inquiry are planned to be finished by September 1992 and forwarded to CEN/TC250/SC1 for its evaluation.

5 CONCLUSION

The present draft gives rules for loads in silos and tanks. The rules are simple and based on well defined physical parameters.

The preparation of the draft is well advanced, and it is expected that the last major changes will be included in a draft by September 1992.

6 REFERENCES

[1] "Silos and Tanks. Outline for part 11". Report for the Eurocode Task Group on Actions on Structures. June 1987.

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[3] Eurocode 1: Basis of Design and Actions on Structures
Volume 4: Actions in Silos and Tanks
Draft, PT8, February 1992, CEN/TC250/SC1