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Defects in accepted methods of estimating design loading for silos

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The Author argues that current codes of practice and guidelines for assessing design loading on silos and hoppers are lacking in some aspects. The object is stated as: 'to point out these defects and to suggest how the design approach can be improved.' We agree that current codes have many defects, but we would argue that this Paper does not help code writers very much.

On stress paths

52. In § 8, the Author states that during filling, the solid 'will be compressed vertically and some horizontal extensive strain will occur'. For a smooth-walled rigid cylinder, the horizontal strain will always be zero. For most real silos, including all the silos the Author studied, a uniform radial strain of 0·1% would be extremely large. A glance at Fig. 1(a) shows that the walls are all very stiff. Hence the most likely condition for initial filling is effectively zero lateral strain. The horizontal pressure ratio differs from K_0 because wall friction causes shearing in the solid, and because the test to measure K_0 does not model the stress history to which the solid is subjected.

53. The Author describes next what might happen when emptying begins, which appears to be founded on one experiment by the Author.[25] To say that stress path OA is in 'a metastable stress state' (i.e. in unstable equilibrium: *vide* Oxford English Dictionary) is quite unfounded. To say that the stresses will tend to assume the K_0 condition under vertical (tensile) strains when the lateral strain is prevented has not been demonstrated and is contrary to many known materials test results.

54. The responses of particulate media are known to be stress history dependent. Many experiments on soils and bulk solids have shown that when the solid is allowed to undergo vertical tensile strain, the horizontal stress can be 'locked-in': the ratio of horizontal to vertical stress K increases and can exceed unity. An example of tests on sand is shown in Fig. 13.[26] There is no 'natural' state at K_0, as suggested in § 9.

55. It appears that Fig. 2(a) demonstrates that K increases on discharge, moving towards the K_0 line at three locations around the circumference chosen 'as they are spaced at 90° to each other'. However, it is very instructive to examine Fig. 6(c), where results at two other levels in the same silo are shown. The left side of the figure shows the filling 'pressures', and the right side shows the discharge 'pressures'. At level 1, three 'pressures' fell substantially, while two scarcely changed. At level 3, three 'pressures' fell dramatically while one rose dramatically.

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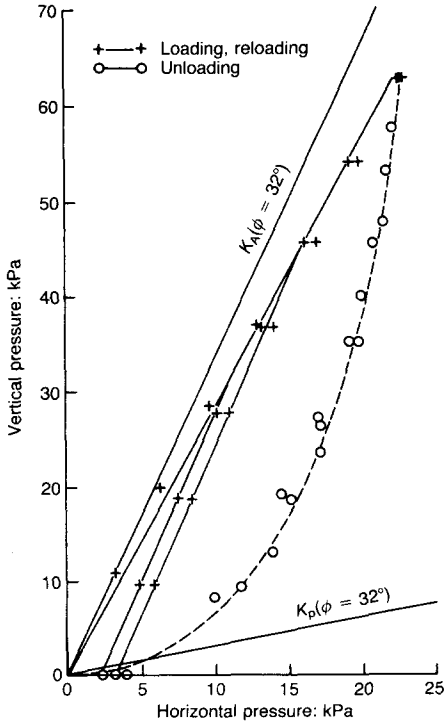

Fig. 13. Stress paths observed in a confined compression test

56. The proposition that the solid is therefore seeking stability under higher pressures resulting from a higher K is clearly untenable. If anything, the mean 'pressure' is falling. Rigorous statistical studies[27] have shown that the mean pressure overall is always close to Janssen, whether the filling or concentric discharge state is being studied. If the Author plotted all the results before he chose to present those of Fig. 2(a), he must have found that there was no general increase in K. It appears that he chose his results very selectively to demonstrate the required proposition.

57. Finally, if a designer were to try to predict the line marked $K_0 \gamma z$ in Fig. 2(a), using the information in the Paper, he would measure the angle ϕ at 41°[8] and use it in equation (1c) to obtain $K_0 = 0{\cdot}374$. The designer would then underestimate the $K_0 \gamma z$ line pressures by 32%. Using equations (1), the value of K_A in Fig. 2(a) corresponds to $\phi = 39{\cdot}7°$, while the value of K_0 corresponds to $\phi = 26{\cdot}1°$. Such an inconsistency needs explanation.

Circumferential pressure variation

58. The horizontal pressure variations in silos and their structural consequences have been discussed at some length before.[8, 10, 27–30] They are widely acknowledged to occur, and the German DIN code[2] has included a procedure to

allow for them for several years. The Author appears to have ignored reference 10 and not to be aware of much of the other literature.

59. The real challenge facing code committees is to find a rationally-based simple codifiable method of including horizontal pressure variations. The new suggestion in Fig. 12(c) may well be suitable, but its superiority over the German 'patch' load has not been established.

Deduction of 'equivalent wall pressure' from strain measurements

60. The Author derived the pressures acting on the walls of the two steel silos from the readings of the strain gauges mounted on the wall. The deduction of pressures from strains in the shell is not a straightforward process. The instrumentation of the steel sugar silo of Fig. 2 is given in reference 8. Bending strains in the steel wall were not measured, and the local circumferential stress σ_θ has been simply interpreted through $\sigma_\theta = \sigma_h D/2t$ as a local pressure value.

61. This process results in wall 'pressures' which are wrong by large and variable margins, often by several hundred percent. The Author appears to try to allow for wall bending by writing: 'The calculated horizontal pressure depends on the assumption that the silo cross-section is truly circular.' (§ 12). A truly circular silo would still experience large bending strains if subjected to the pressures plotted in Fig. 6(c).

62. In an attempt to investigate the magnitude of the ignored bending for this case, we analysed the silo of reference 8, subject to the pressure distribution given in Fig. 6(c), and using the geometry defined in reference 8. The bending strains (which were assumed to be zero by the Author) were found to be larger than the circumferential membrane strains (which were assumed to be being measured), so that the inferred pressures are probably wrong by more than 100%.

63. However, to make matters worse, the calculations showed that the strains at level 1 depend quite sensitively on the adjacent boundary condition of the bottom of the silo wall, so any strain measured at this point can be interpreted only if a complete structural analysis of the silo is used. Accordingly, most of the huge variation in pressures which the Author plots in Fig. 6(c) probably arises from bending of the wall under smaller unsymmetrical pressures, and not from large variations in pressure. The variations shown in Fig. 6(a) and (b) are more credible, but the reader is not told whether these are peak values, values at one instant, or maximum and minimum values. It is difficult to know, therefore, how they should be used to develop a design rule.

64. The Author appears to have some inkling of these difficulties when he writes in § 26: 'it is believed that much of the apparent radial variability of pressure is, in fact, radial variability of strain arising from geometrical imperfections'. If the inferred pressures in Fig. 6(c) are in error or exaggerated by geometric imperfections, how can so much faith be placed in the readings shown earlier in Fig. 2?

Misinterpretation of arching and wall friction

65. The proposition that 'arching may or may not occur and may break down' (§ 11) is central to the Paper. Unfortunately, almost all the evidence for the loss of arching is obtained by misunderstanding or misinterpretation.

66. As a first example, § 16 states: 'It will be noted that the angle of wall friction developed on path 5–5 during filling was about 12°, as compared with the full angle of wall friction of 32°.'. If the value at the point marked in Fig. 2(b) is used, together with the density[8] of $\gamma = 8{\cdot}6$ kN/m^3, the value of K which has been

used in backfiguring this wall friction can be found as $K_0 = 0{\cdot}55$. As the silo was being filled, and the pressures were clearly much smaller (Fig. 2(a)) than this $K_0 \gamma z$, it is quite misleading to use this K_0 to backfigure the wall friction, and so to deduce a low wall friction value.

67. If, instead, Janssen's equation is used with a sensible value of K of perhaps 0·3, the full wall friction is found to predict the curves 5 and 6 very closely. Thus, the curves in Fig. 2(b) do not show that wall friction is poorly developed. Instead, they show that Janssen's equation (involving wall friction and arching) gives much better predictions of the measured vertical wall loads than the Author's procedure.

68. Next, the Author infers (e.g. § 18) that high pressures arise from low local wall friction ('the upper limit to the measured horizontal pressures reveals that there was relatively little arching at this depth'). By studying the equilibrium of the entire silo, it can easily be shown that neither the pressures nor the wall load respond quickly to local changes of wall friction (Fig. 14). Loss of arching is not a viable explanation of the high pressures.

69. The most probable reason for the inverse correlation between the measured circumferential strain on the outside of the wall and the deduced value of vertical wall load (§ 13) lies in the structural behaviour of a cylindrical shell under unsymmetrical local normal loads, which induce vertical membrane stresses in the wall as well as circumferential membrane stresses, and both vertical and circumferential bending stresses.[31] The behaviour is very complicated and cannot be described within this discussion.

Mean vertical stress in the stored solid

70. Several plots show the changes to the deduced pressure and the wall vertical load at a point as the 'overburden pressure' (γz) increases.

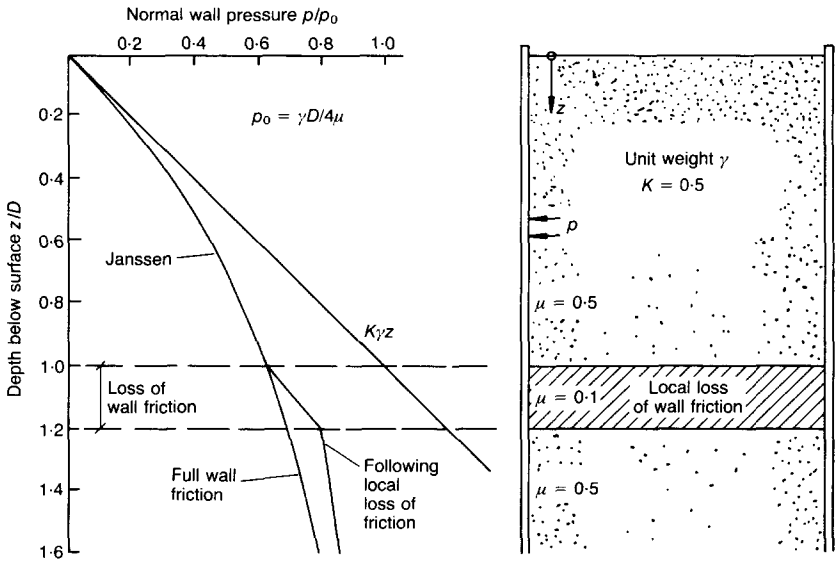

Fig. 14. Effect of local loss of wall friction on pressures

71. If the wall load from friction at a certain level is known, then the mean vertical stress in the solid can be found from the difference between the weight of bulk solid and the frictional wall load at that level, divided by the silo cross-sectional area. Thus, if there is any friction on the wall, the vertical stress at the level will be less than γz.

72. Frictional wall loads developed in all the experiments. It is misleading to plot pressure and wall load against γz and to state that this plot shows a stress path (§ 12). No mention is made of this simplifying approximation.

Wall pressure profiles and plots of 'stress path'

73. Although the assumption is not directly stated, the Author appears to have interpreted the 'stress path' at a point on the wall during filling (e.g. Fig. 5) as identical to the wall pressure profile above that point at the end of filling.

74. Many experimental observations have shown that the changes in wall pressure at a point during filling can be very different from the actual pressure distribution on the silo wall.[32] This can also be demonstrated from the results presented in the Paper. Accordingly, if the curve for generator 5 in Fig. 2(a) (level 2) is used to predict the pressure which this inference indicates should have occurred at the end of filling at level 3, the prediction is found to be 41 kPa. The measured value (Fig. 6) was only 29 kPa, so the inference shows an error of 41%. The wall pressure distribution cannot be inferred from pressure changes at one level.

Linear K_A or K_0 profile

75. The Paper does not distinguish between tall and squat silos. The silos of Figs 2, 4 and 5 are all moderately squat (effective H/D around 1·5). In a squat silo, the linear hydrostatic pressure distribution and the Janssen distribution are experimentally almost indistinguishable. Therefore, these are not good experiments from which to argue about whether or not arching is occurring. For moderately deep and deep silos (Fig. 3), the $K\gamma z$ lines give extremely large wall pressures which are most unlikely to occur in practice. The 'spread' of pressures (§ 17) shown for the silo of Fig. 3 disguises the fact that the mean pressure distribution overall, as found from the original raw data, is very close to the Janssen distribution.

Pressures in hoppers

76. The Author's casual treatment of the mechanics of hoppers (§ 33), even ignoring the orientation of the hopper wall, must be left for others to answer. However, it should be noted that his two main criticisms of earlier work were that the material could not change rapidly from an active to a passive state at the transition, and that existing theories assume that plane sections in the cylinder remain plane in the hopper.

77. It is easy to believe that an active to passive change must occur rapidly below the transition in a normal conical hopper if one examines the change in cross-sectional area which occurs here (Fig. 15). Huge strains (by Fig. 1(a) standards) must occur immediately below the transition. The same is not true for an inverted cone silo (Fig. 4), and the suggestion that no switch may occur in this silo is quite reasonable.

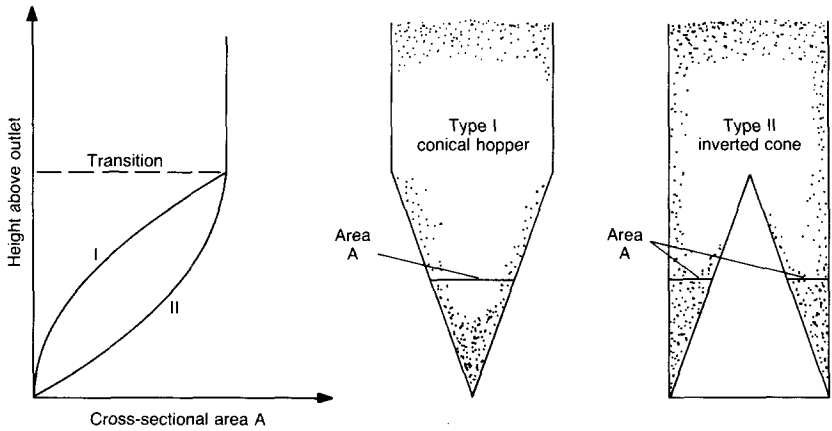

Fig. 15. Variation of cross-sectional area for conical hopper and inverted cone

78. The second criticism muddles static and kinematic considerations. The quoted existing theories make no assumptions about plane sections, but insist merely that equilibrium must exist in any slice of material. They do not exclude material from queuing to exit the silo.

79. The reader should note that the pressure comparisons given with Walker's theory and the Australian code omit their predictions of filling pressures, which are much closer to the test results. It is not clear what the Author means by 'no arching' in a hopper. Can he believe that bulk solid is sliding out of the hopper without the full wall friction developing between the solid and the wall?

Temperature surcharge pressure

80. In § 28, the Author states that the equation attributed to Andersen 'appears to give unrealistic results' and he develops a 'new' equation in the Appendix, based on the assumptions which Andersen used. However, the Author's equation is, in fact, the same as Andersen's equation, with the material parameter M substituted for Andersen's more identifiable but otherwise similar material parameter $E_s(1 - \nu)$.

81. If the 'new' equation (2) is divided top and bottom by $2Mt$, and $D/2$ is recognized as the radius R, then equation (2) is identical to Andersen's equation, as given in reference 3.

G. Mathieson, *Charles Scott & Partners*

It has been clear for many years that silo design methods have been less accurate than one would like: for instance, close inspection of prestressed concrete silos designed by traditional methods often shows up significant horizontal and vertical cracking that cannot be explained other than as a result of design shortcomings. This Paper represents an important and valuable addition to the literature on the subject.

83. One particular aspect of the problem that is touched on in the Paper is the question of the effect of geometrical irregularities in the silo wall on the theoretical stress distribution. Such irregularities can have a highly significant effect on stress distribution in thin walled structures, as has been shown by work on the design of hyperbolic shell cooling towers.

84. Excessive stress resulting from such dimensional irregularities has probably been responsible for several collapses, including that of the cooling tower at Ardeer some years ago. It is therefore of vital importance to ensure that setting out and construction techniques are suitable to attain the degree of geometrical accuracy that is required. The designer must also consider the effect of inevitable irregularities, and ensure that the contract spells out clearly the dimensional tolerances that must be maintained in each particular case.

Dr M. J. Blackler, *Mott MacDonald*

In the Paper, the Author sets out to highlight, by reference to measurements on full-scale silos, defects in the assumptions behind the derivation of ACI, DIN, Australian and EP silo codes. The Author suggests a method for the prediction of silo wall loads which simplifies existing design methods. However, the benefits of the simplified method to the practising engineer are not convincingly presented, nor are they robustly derived. Some of the reasons are outlined below.

86. It is apparent from Figs 3 and 4 that the simplified formula will result in conservative over-prediction of horizontal pressures on the vertical cylindrical wall, and that existing codes using actual material properties will give more realistic estimates. This may not be too important for small capacity silos, but is critical for the economic design of large-scale installations. It also goes against the successful use of modern silo codes in designing safe and functional structures.

87. Full-scale pressure measurements in silos, taken by the Author and other researchers, represent conditions acting over a small area of the wall only. The occurrence of local peak pressures, which are known to occur in practice, can pose problems with data analysis unless there is sufficient instrumentation to define the rate of pressure variation. This is because the structural significance of local overpressures may be small in comparison with the effects of a more gradual variation that has reduced amplitude. The consequence of ignoring localized pressure peaks, by enveloping the measured data, is to over-design the silo for in-plane loads, but this could misrepresent the bending effects.

88. The results presented in Fig. 6 illustrate that silo pressures may not be radially uniform where nominally concentric flow is deemed to occur. Variations in pressure around the circumference are understood to be influenced by such factors as geometric imperfections, method of filling and discharge, eccentricity of outlets, use of mechanical discharge equipment and inherent variations within the stored medium. Because of these many factors, especially the method of discharge in multi-outlet bins, the sin 2β pressure variation suggested in equation (3) may be inappropriate. For silos with central filling and central discharge, it would be better to specify a nominal design bending moment, and for other configurations, to base the radial variation on consideration of potential flow patterns.

89. Pressures derived from surface strain measurements, such as reported in Fig. 5, can be used to bridge the information gap between measured silo loads and their interaction with the silo structure. However, in using this approach, it is necessary to monitor closely the rate of strain variation over a circumference and

to identify wall bending effects (particularly at points of discontinuity, such as stiffeners, ring beams, lap joints, etc.). Where this is not done, extrapolated pressure profiles may be largely in error because of the nature of the necessary simplifying assumptions.

90. In summary, some of the shortcomings of the Author's suggested design method are seen to be:

(*a*) no readily apparent benefit to the overall design effort over traditional methods which form the basis of modern codes
(*b*) over-prediction of horizontal pressures, against realistic prediction by existing methods when actual material properties are used
(*c*) the need to relate more closely the radial pressure variation to silo flow behaviour.

Professor Blight

In § 52, *Professor Rotter* states that the most likely stress condition for initial filling is one of zero lateral strain. His implication is that if the measured horizontal pressure ratio differs from K_0, the measurements must be wrong. However, he fails to appreciate that the material in most silos is placed in an active (K_A) condition and, in terms of Fig. 1(a), has to undergo strain to reach the K_0 condition. This strain occurs in the silo filling, and not in the wall of the silo.

92. The active state is a state of failure, with shear stresses at the maximum for the prevailing direct stresses. The stable condition for vertical compression under zero lateral strain is the K_0 state, as Rotter states in § 52. If shear stresses in the filling are larger than those corresponding to the K_0 state, as they are along stress path OA in Fig. 1(b), they will, given the opportunity, reduce to those of the K_0 state. The start of emptying causes vertical tensile strain in limited parts of the filling, depending on the flow pattern. It also allows lateral strains to occur in the filling that, in turn, reduce shear stresses and allow stress path AB to occur. This very process is illustrated in Rotter's Fig. 13, where the stress path starts out on the K_A line and progresses towards the K_0 line, reaching the K_0 line only when the vertical stress has been increased to 45 kPa.

93. In § 54. Rotter again demonstrates misunderstanding. If the process depicted in his Fig. 13 were to be followed on a pressure cell set in the wall of a silo, it would be observed that, as emptying starts, the horizontal pressure is virtually unchanged. The observer would have no knowledge of the vertical stress changes and would therefore conclude that the stress ratio was not changing. Studies of strain conditions in silos at the start of emptying (e.g. Deutsch and Clyde,[21] show that strain conditions hardly change in the silo filling, except in the immediate vicinity of the outlet. There must be dramatic stress changes here, but elsewhere the lack of changes in strain shows that all vertical and horizontal stress changes must be modest, as indicated by stress path AB in Fig. 1.

94. In Rotter's §§ 55–57, I am accused of being selective in my choice of data. On reviewing Rotter's evidence for this accusation, I admit that he appears to be correct. However, in attempting to confound, Rotter has committed the very sin of which he accuses me. If he had read reference 8 less selectively, he would no doubt have noticed that an error has been made. The diagram that appears as Fig. 6(c) actually shows radial distributions of frictional wall load, not equivalent horizontal pressure. The correct version of Fig. 6(c) is given here. This figure shows that in

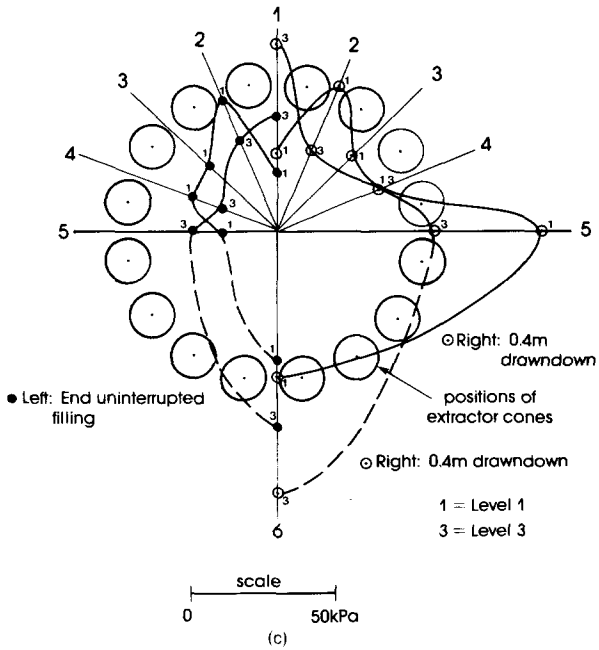

Fig. 6(c). Corrected version

every case, except one, the equivalent horizontal pressure increases on drawdown. Rotter would also have seen that there is a separate figure in reference 8, similar to his Fig. 13, that shows that K_0 for normally consolidated sugar was measured at 0·55. It is hoped that the hypothetical designer would have used this value, rather than equation (1c), which is clearly denoted as empirical and approximate.

95. In Rotter's § 58, I am accused of ignoring reference 10. This is hard to understand as the reference has been listed in the Paper and Fig. 3 is acknowledged as coming from that source. With regard to references 27–30 (three are Rotter's), 27 was published after the Paper was written, 28 appeared in the proceedings of an obscure conference, 29 is in German, and 30 was never published.

96. Rotter's §§ 58–64 were clearly written by an analyst who has never tried to make any sort of field measurement. If he had, Rotter would have known that access to all heights of the outside of a large silo is very difficult to obtain. Access is available only if scaffolding has been erected for the purpose of applying insulation or of painting, or if a tower crane is available, so that one can work dangling from a basket. Access to upper heights of the inside of the wall of a roofed silo is just not practically possible. Application of strain gauges to the inside of the walls of a silo is even more difficult, as the wall frictional forces scrape off the gauges and their connecting leads. Storage silos for foodstuffs and other perishable commodities have to be waterproof. For this reason, owners of these silos are reluctant to allow holes to be drilled in the walls of their structures. One therefore has a dilemma.

Either one accepts that it is not possible adequately to measure strains on working steel silos and interpret them in terms of pressures, or one makes the best possible attempt under the circumstances. The equivalent horizontal pressures and frictional wall loads shown by me in Figs 2, 5, 6(a) and 10 are at least numbers that, if multiplied by suitable factors, will give the principal strains measured on the outside of the relevant silo walls. It follows that strain calculated in a design situation from pressure distributions established by this means will give strains of the same nature as those measured on the outside of the test silo. Despite Rotter's objections—which, it should be noted, are based on approximate theories—these pressures cannot be completely unrealistic.

97. I have now developed a method of protecting strain gauges mounted on the inside of silos having corrugated steel walls. It turns out that pairs of back-to-back readings are quite similar. This casts at least some doubt on the validity of Rotter's criticism. However, do not take my word for it. A recent comparison by Borcz and el Rahim[33] of pressures derived from strains measured on the outside of a steel silo, with pressures measured by means of pressure cells, has shown very good agreement between the two sets of measurements. The fact of the matter is that individual panels composing the walls of circular steel silos are extremely flexible. Initial out of roundness in these large flexible sheets is largely corrected when the internal pressure is first applied and thereafter does not affect strain measurements.

98. If strains measured on one side of the wall of a steel silo cannot be used to estimate internal pressures, why are similar results obtained whether strain measurement or pressure cells are used on steel silos?[8,25,33] Furthermore, why are similar results obtained when pressures are measured using pressure cells on reinforced concrete silos? The data shown in Fig. 3 (which Rotter does not attack) are very similar to those shown in Fig. 5 (which he does attack). Why can the suggested methods be used to calculate reasonable envelopes to data from both pressure cells and strain gauges if the strain gauge method is hopelessly wrong?

99. In § 66, Rotter refers to 'Fig. 2(b)'. It is presumed that he refers to point 5B on the wall load diagram to the right of Fig. 2. A corresponding point 5B is shown on the left-hand diagram for equivalent horizontal pressure. This point lies very close to the $K_0 \gamma z$ line for $K_0 = 0{\cdot}55$. Hence, it was quite correct to back-figure the angle of wall friction for this value of K_0.

100. Rotter's argument in § 68 and his Fig. 14 are not convincing. Fig. 14 shows a 10% increase in horizontal pressure resulting from a hypothetical loss of frictional resistance over a limited height of silo wall. Fig. 3, to which he appears to be referring, shows a 23% increase in pressure at a depth of 30 m. By adjusting the numbers he has selectively used in his example, a 23% increase could equally reasonably be demonstrated.

101. Referring to Rotter's §§ 70–72, the term 'overburden stress' is commonly accepted as meaning 'depth above point considered multiplied by unit weight of material'. This is clearly shown wherever the term has been used in the Paper. Nowhere is there any suggestion that overburden stress equals vertical stress.

102. Rotter's §§ 73 and 74 are also uncalled for: wherever a diagram in the Paper refers to changes of pressure or wall load at a point, it is quite clearly marked as a stress path. Full pressure profiles are not thus marked.

103. Rotter may be correct in saying in § 75, for the specific case illustrated in Fig. 3, that pressures near the base of the silo will never reach the linear $K_A \gamma z$ profile. However, in the vicinity of 30 m, at which depth the H/D ratio is 4 to 4·5,

pressures not only reached the $K_A \gamma z$ line, they exceeded it. Thus it is obviously possible for a linear pressure–depth profile to occur in a tall silo. A linear profile also does not always occur in a squat silo. It does not apply in Fig. 4, where the silo concerned has an H/D ratio of 2 to 2·5.

104. With reference to § 76, I fail to see in what respect I have ignored the orientation of the hopper walls. The slope of the hopper is clearly marked in each case, and the pressure normal to that wall is given. In §§ 77–79, Rotter shows again that he does not understand the implications of his Fig. 13 or how material flows out of a hopper. The flow can occur without significant change of pressure normal to the hopper wall because the material queues to exit and because, in terms of Fig. 13, there is little change in horizontal pressure accompanying a reduction in vertical pressure. Rotter's Fig. 15 becomes relevant only if the material crowds into the outlet, thus undergoing lateral compressive strain and increasing the lateral stress ratio in the process. It does not do this, and hence filling pressures remain unchanged at the start of emptying in structures such as those illustrated in Figs 9–11. In these structures, the material adjacent to the hopper walls is not intentionally disturbed during emptying. However, in the case of the structure shown in Fig. 4, the material is disturbed during discharge by the injection of compressed air. Here there is a marked reduction of pressure towards the outlet.

105. Referring to Rotter's §§ 80 and 81, I have nowhere stated that equation (2) is new. It is different from Anderson's equation in two respects: firstly, it lumps uniaxial elastic and Poisson's ratio effects together into the compression modulus M; secondly, M has so far been derived from field measurements. This recognizes that the compressibility of granular materials is highly strain-dependent and needs, in this instance, to be measured in the range 0–200 microstrain. Although this can now be achieved in the laboratory (e.g. reference 34), the technique is new and I do not yet have the apparatus to carry out this type of measurement.

106. With regard to *Mr Mathieson's* comments on the effects of geometrical irregularities, I would agree that the latter are certainly important for hyperbolic shell cooling towers, but are possibly less so for silos where the loading is to a certain extent supportive of the shell.

107. In respect of *Dr Blackler's* discussion, it is certainly true that the Janssen theory gives results that are quite satisfactory for some silos: Fig. 4 illustrates this. However, the argument is not as convincing for Fig. 3. The difficulty the designer faces is knowing beforehand when Janssen will apply and when not.

108. I would certainly endorse Blackler's remarks concerning the use of actual, properly measured material properties, where these are available. Often, however, silos have to be designed and constructed before the product they are intended to store has been produced. In these circumstances, how does one know if calculated pressures will be conservative?

109. Blackler's point in his § 87 is well-taken. It would, however, be useful to have some suggestions as to how to overcome the difficulties inherent in extrapolating from spot measurements. The same comment applies to his § 89. Unfortunately, there is always a gap between what is practically achievable and what is theoretically desirable. Availability of resources usually dictates the former.

110. Referring to §§ 88 and 90, I have made some suggestions for what I consider to be improvements to existing design codes. Research and learning should be an ongoing process. The suggestions in the Paper are certainly not seen as the last word on the subject, but only as a step on the way to improved engineering knowledge of silos.

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