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Service Problems with Steel Bins

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Probleme beim Betrieb von Stahlbunkern
Problèmes d'entretien des silos d'acier
Problemas de entretenimiento vinculados a los silos de acero

スチールサイロの保守問題

钢制地下仓的保养问题

مشاكل الخدمة المرتبطة بالصوامع الفولاذية

Summary

During the past ten (10) year period from 1970 to 1980 there have been eleven partial or complete failures of coal storage bins at locations on the surface and underground in N.S.W. coal mines. A number of these failures have resulted in loss of life to workmen.

Several factors have emerged from investigation of these failures which have either individually or collectively been the cause of the failure. This paper attempts to identify these factors by reference to relevant details of the failed structures.

The absence of a suitable design code or code of practice covering the design, construction and maintenance of elevated bulk solid storage containers, has led to standards being adopted which were not satisfactory.

It is therefore vitally important that a suitable design code be prepared or additional requirements inserted in existing structural codes to cater for the peculiar operating conditions within bulk solid storage containers.

1. Introduction

The design of elevated bulk solid storage containers has been traditionally carried out using techniques adopted for other classes of structures.

When in use, a bulk solid storage container will require more maintenance than other classes of structure because of wear, corrosion and fatigue.

The N.S.W. coal mining industry has for many years been able to cope with these problems by adopting designs which were robust and had adequate margins of safety (heavily framed structures with — usually timber — lagging for containment of the bulk solid).

Economic pressures have led to the introduction of lighter, more cost efficient structures in which the container also forms part of the support structure.

The prediction of loadings imposed on the structure during filling and emptying of the container have quite often been in error, due to a lack of understanding of the flow properties of the bulk solid and the effect of bin geometry on the flow patterns produced.

During the period between September, 1970 and April, 1981 there have been eleven partial or complete failures of bulk storage containers in N.S.W. coal mines that have been investigated by the Department of Mineral Resources.

Three of these failures resulted in fatal injuries to workmen engaged in driving vehicles used to unload the containers or servicing machinery installed under the container.

Analyses of these failures has indicated several factors which have either individually or collectively been the cause of the failure.

These factors can be summarised under the following headings:

1. Design deficiencies.
2. Unsatisfactory specifications for the original structure.
3. Errors in the preparation of construction drawings.
4. Errors in manufacture and/or erection of the structure.
5. Lack of regular inspection and proper maintenance during the life of the structure.

2. Design Deficiencies

Four dominant factors have emerged and these will be discussed with reference to pertinent details of cases analysed.

1. Lack of knowledge regarding the loads imposed on the structure when bulk materials were conveyed into a storage bin was illustrated by the collapse of an underground run-of-mine coal bin hopper.

   This hopper failed due to shearing of bolts in a bolted joint between the hopper back plate and side plates.

   Because the bin was allowed to completely empty, it was possible for large lumps of coal or rock to fall a distance of 35 m before coming to rest against the bin hopper plating.

   Depth probes installed to prevent complete discharge of the bin contents plus additional buffer beams in the bin were used as means to prevent a similar occurrence.

2. Vibrations transmitted into a bin cone section from a vibrating feeder supported directly on the cone shell plating is considered to be the cause of weld failures in at least one bin collapse.

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Examination of welded joints suggested that fatigue failure of the weld to parent metal interface had occurred.

A separate support system for the vibrating feeder would have prevented resonant forces being transmitted into the bin structure as well as providing the feeder with supports of constant damping characteristics.

3. Lack of experience in structural principles.

It is not uncommon to see bin support structures with missing or damaged bracing components.

Many factors influence the amount of bracing, provided in a bin support system, to resist lateral and rotational forces.

Some of these are:

a) The need to provide access for trucks.
b) Provision of uninterrupted space for cleaning up operations.
c) Reliance on rigidity of connection between the support columns and their foundations.
d) Cost of fabrication and erection.

At least one structure which was analysed had been erected without any bracing in the plane of the support columns.

The designer had relied on the development of restraining moments at the support column base plates to provide stability of the structure.

Stability of the structure was upset when the foundation failed under one (1) of the four (4) support column base plates.

In another case the partial failure at support column connections allowed a bin and dump truck bridge structure to settle approximately 30 mm.

The design of the particular connection required large concentrated loads to be transmitted through the webs of universal beam and column sections which were separated only by a thin steel plate (Fig. 1).

Buckling of the web of the vertical member attached to each corner of the bin allowed the bin and road bridge to drop by up to 30 mm maximum (Fig. 1a).

Fabrication of a stiffened connection stool between these two members would have avoided this failure.

4. Unsatisfactory design and location of site joints has been evident in a number of failures.

Where site welding is to be carried out underground in coal mines special precautions are required to prevent a serious hazard developing.

It is reasonable to say that site welding in underground conditions is never as satisfactory as site welding at surface locations.

For this reason site joints should be located at points of minimum stress concentration, particularly where welding is used.

The failure of an underground run-of-mine coal storage bin cone section was found to be at a joint which had been site welded.

This joint was located at the upper edges of the cone plate where it met a heavy steel support beam (Fig. 2).

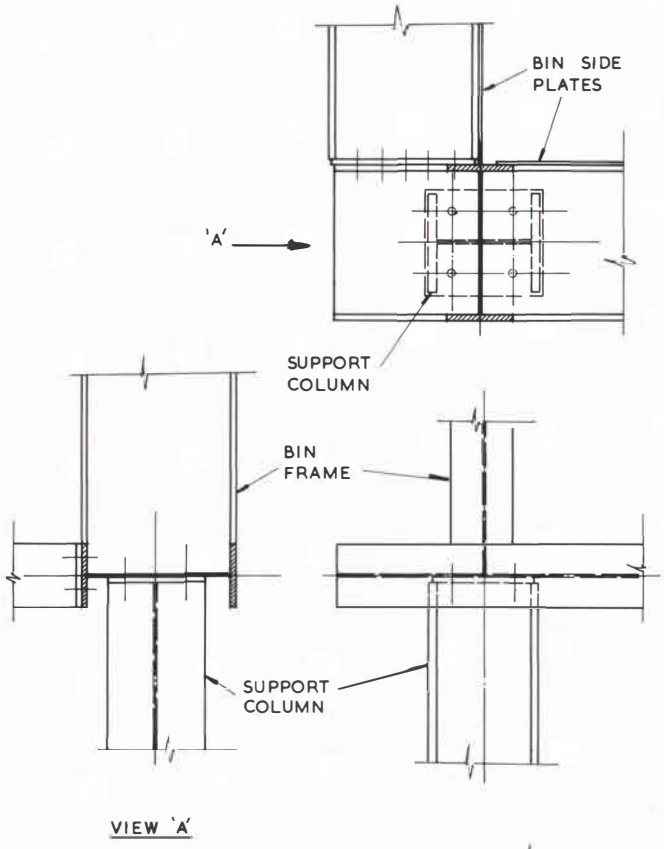


Fig. 1

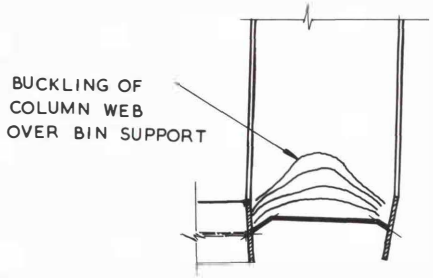


Fig. 1a

When the bin was placed in service this joint was buried under coal and was exposed to maximum flexural stresses as the hopper was filled and emptied.

Examination of the welded joint indicated that a large portion of it had been cracked for a considerable period of time before the hopper failed.

A similar failure occurred on a surface product coal bin and after examination of other structures in the same complex the product coal storage bin had to be emptied and taken out of service for repairs.

3. Unsatisfactory Specifications

Unsatisfactory specifications and control of the construction of elevated bulk storage containers has been found to be the cause of failures because of the resultant poor quality of workmanship.

Where the work is correctly specified both the contractor and the owner are aware of their responsibilities under the contract.

Contractors have too often been left to set their own standards for the design and construction stages. This has resulted in no one person being responsible to ensure that a safe structure is erected.

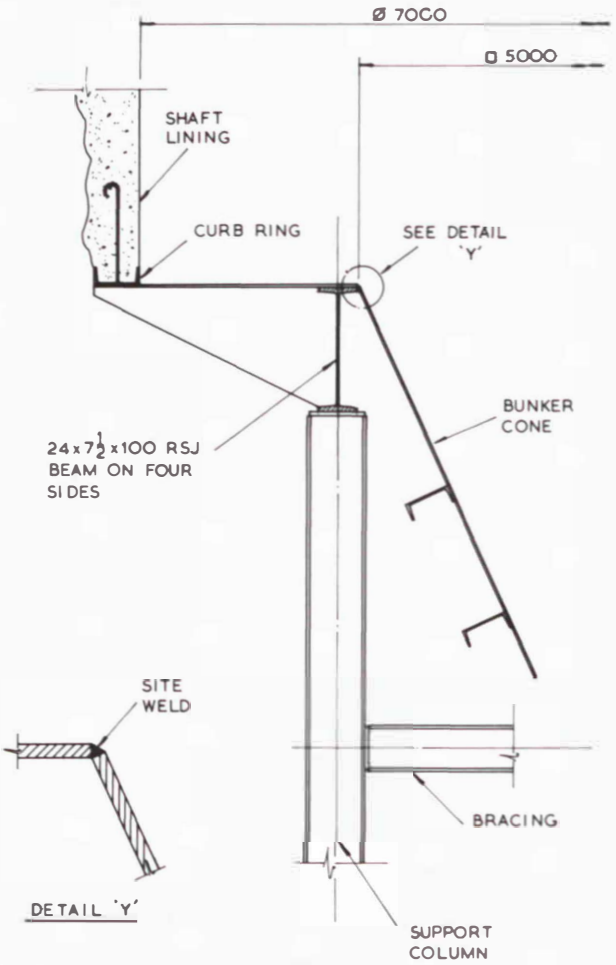


Fig. 2

Analyses of the collapse of a bin and its support structure indicated that failure of a concrete foundation slab could have allowed settlement of a support column.

The upper portions of the foundation contained fine material which was easily broken, while the coarse aggregate had settled into the lower portions of the foundation.

This concrete could not support the concentrated loadings transmitted by the sharp edges of steel packing used under the column base plates.

Because the contract had been executed on an *ad-hoc* basis, details of the construction programme were not readily available to assist the investigation.

The importance of an adequate specification for the work and maintenance of records during construction has proved to be very useful on a number of occasions where failures have occurred.

4. Errors in Construction Drawings

Errors in the preparation of construction drawings was found to be the cause of partial failure of one surface run-of-mine coal storage bin.

The design of the bin required that the column section be continued into the ring beam.

A further complication was introduced by a vertical bolted joint in the bin cylinder and cone sections, located at each column position.

The bin as constructed was provided with flange plates at the edges of each section of the bin to facilitate joining by bolts on site (Fig. 3).

In the area over the column connections and in the ring beam section this flange plate was not stiffened at its outer edge and therefore buckled under the concentrated column loading (Fig. 3a).

5. Errors in Manufacture

Errors in the manufacture and or erection of a large refuse bin at a coal preparation plant is considered to be the main cause of failure of this bin.

Details supplied indicated that the bin was required to be supported at eight (8) points equally spaced around the bin at the ring beam.

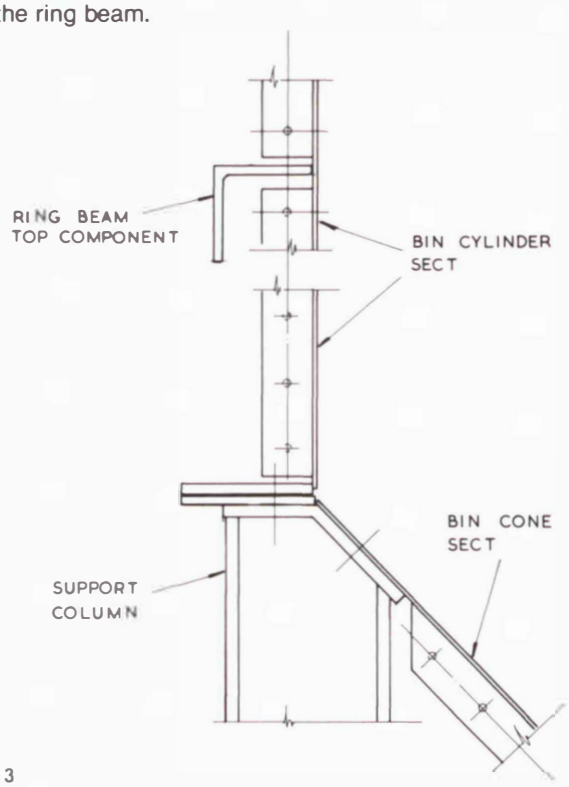


Fig. 3

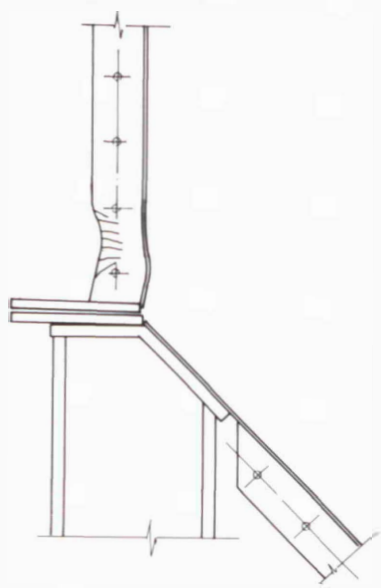
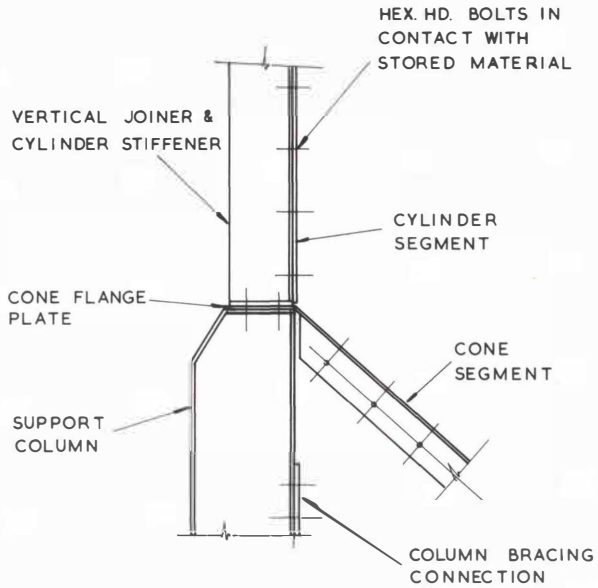
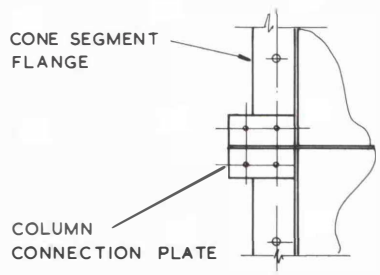


Fig. 3a





These connection points were to be supported on a system of horizontal beams forming an octagonal array which in turn were supported on suitably braced columns.

Examination of the failed structure indicated that only four of the supports had been provided, thereby increasing the load transmitted to the connections provided.

6. Lack of Regular Inspection

Lack of regular inspection and maintenance is one of the most common problems with coal storage bins at coal mines in N.S.W.

There has been a distinct lack of appreciation of the need to carry out regular inspections of critical areas of the bin and its support system.

Because of the corrosive nature of coal coupled with abrasion by the mineral as it moves in and out of the bin, frequent repairs and replacement of bin shell plating is required.

However, when these repairs are carried out other factors affecting the security of the structure have usually been neglected.

Problems which have been found which can be attributed to lack of maintenance are:

1. Erosion and corrosion of bolts at seam joints, particularly where these bolts are in contact with the stored material.
2. Failure of welded joints between the flanges of the bin cone and cylinder sections particularly at the cone to cylinder transition.
3. Failure of the bin to column connections resulting from corrosion and fatigue of welded joints.
4. Failure of support column foundation bolts by corrosion or by damage from mobile equipment used in cleaning up operations.

A recent collapse of a run-of-mine coal storage bin and its support structure at a surface location was a good example of how a structure of this type can deteriorate and go undetected when regular inspections are not carried out.

The particular bin was an old structure which has been re-used at a number of locations.

At the time of collapse it had been erected at the one site for twelve (12) years. Apart from repairs to shell plates and cone plating to prevent leakage of the stored material no other repairs had been reported.

Examination of the failed structure indicated that the bin to column connections had deteriorated, because of corrosion and fatigue of welded joints, to such an extent that bin settlement had occurred. The extent of this settlement was probably sufficient to allow contact between the unloading door frame and truck body passing under the bin.

7. Conclusions

The failure of this type of structure at coal mines in N.S.W. has focused attention on the inadequacies of procedures used for the design, construction, erection and maintenance of coal storage bins.

Many operators have carried out thorough inspections of their installation which have revealed the need for expenditure of large sums of money to affect satisfactory repairs.

More recently, designs for this type of structure have been prepared on loading predictions determined from the methods developed by P.C. Arnold, A.G. McLean and A.W. Roberts [1].

However, the design principle applied are those used for other structures, which should be satisfactory if adequate consideration is given to the problems of corrosion and erosion.

The most important aspects of the use of elevated storage structures for bulk solids can be summarised as follows:

1. The use of sound engineering principles in the determination of design parameters such as loading conditions.
2. The development of a reliable design guide for the proportioning of the structure components.
3. Introduction of satisfactory inspection procedures which are designed to tests the fitness of the structure for continued use.

The coal industry generally produces aggressive conditions for steel structures and therefore any improvement in the corrosion resistance or protection of the basic construction materials will have a marked effect on the frequency of failures resulting from neglect to carry out maintenance.

The author is of the opinion that the availability of a design standard or code of practice would go a long way in reducing the problems which have, been outlined in this paper.

References

[1] Arnold, P.C., McLean, A.G. and Roberts, A.W., "The Design of Storage Bins for Bulk Solids Handling". bulk solids handling Vol. 1, 1981, No. 1, pp. 13—23.