LIMESTONE STORAGE IN MODERN STEEL DESIGN
FOR CEMENT PLANT IN INDONESIA

Figure 1. Interior perspective view of limestone storage.
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STEEL DESIGN FOR CEMENT PLANT
IN INDONESIA

BY

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Figure 2. Perspective view of limestone storage.

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SUMMARY

This paper presents a description of a light weight steel structural system applied in a wide span storage for lime- and claystone used in 1970 on a new cement factory in the vicinity of the city of Padang, Indonesia. Considering the special loading conditions including a transport bridge system suspended from the hall centre and earthquake loads the structural system has proved its efficiency by achieving a unit steel weight of only 4.80 kg/m$^3$ hall volume.

The pronounced features are adequacy for fabrication by local labour of medium size welded elements and the application of merely bolted joints in all subassemblies and erection joints. Further a special rafter system has been introduced combining light weight cold formed C-shaped purlins and rectangular hollow sections. The system has thereby met the basic requirement for easy transportation and erection as well carried out by local labour under guidance of Danish site engineers.

ZUSAMMENFASSUNG

Diese Schrift beschreibt ein Stahlkonstruktionssystem in Leichtbauweise, dass für ein weitgespanntes Kalk- und Tonsteinlager in 1979 auf einer neuen Zementfabrik in der Umgebung von der Stadt Padang, Indonesien, verwendet worden ist. Wenn die speziellen Lastverhältnisse einschliesslich Erdbeben und ein im Lagermitte aufgehängtes Förderbandbrücke beachtet werden, hat das System mit einer Stahlgewicht von 4.80 kg/m$^3$ Hallenraum seine Effektivität bewiesen.

Die grundsätzlichen Eigenschaften des Systems sind die Anpassung zur lokalen Herstellung von geschweissten Elementen in Mittelgrösse und die Verwendung von Schraubenverbindungen in allen Montagestossen.

Ein spezielles Riegelsystem ist hier introduziert worden, in welchem C-Kaltprofile und Rechteck-Hohlprofile kombiniert werden.

Das System ist dabei die grundsätzlichen Förderungen zum problemfreien Transport angepasst und darüber hinaus ist auch der Wunsch zu einer leichten und schnellen Montage mit Verwendung von örtlicher Arbeitskraft erfüllt worden.

SUMARIO

Este artículo presenta una descripción de un sistema estructural ligero aplicado a un almacén de gran envergadura para piedra caliza y arcillas, puesto a punto en 1979 en una nueva fábrica de cemento en las cercanías de la ciudad de Padang, Indonesia. Considerando las condiciones especiales de carga, incluyendo acciones sísmicas, así como un sistema de puente para cinta transportadora suspendido en el centro de la nave, el sistema estructural ha demostrado su eficiencia logrando un peso unitario para la estructura de acero de tan sólo 4.80 kg/m$^3$ de volumen de la nave.
Las características más pronunciadas de la estructura son la indoneidad para su fabricación por mano de obra local, en elementos soldados de tamaño regular así como la aplicación de uniones atornilladas puras en todas las subuniones y uniones de montaje. Además, un sistema especial de entramado de cubierta ha sido introducido, combinando correas de perfiles ligeros en C, laminados en frío y perfiles laminados tubulares rectangulares. El sistema ha así satisfecho el requerimiento básico de un transporte y erección fáciles llevados a cabo por mano de obra local bajo la supervisión de ingenieros daneses en la obra.
1. INTRODUCTION.

The storage facility in steel here described house a fully automated handling system for raw material used in the fabrication of cement. The storage capacity of 40,000 t. is rather small compared with the size of the hall because of the space demands for longitudinal and transverse handling equipment. The storage is part of a new cement plant under construction in the vicinity of the city of Padang on the west coast of Sumatra, Indonesia. The total covered floor area of the hall is 7,550 m² and the volume 126,000 m³. As the total consumption of steel is 497 t. exclusive the transport bridge the amount of steel per m³ volume is only 3.95 kg. This evidently low steelweight was achieved by the choice of a favourable structural system for the cladding support system as well as for the primary structural planes. The steel material for the structure was supplied from Europe whereas the fabrication took place not far from the building site, on a provisional partly open air plant area, with a rather simple equipment of tools and cranes. Intensive quality control and advisory service offered by the Danish supervisors was therefore important to meet the requirements for quality and accuracy expected from the designers office. The conveyor bridge supplying the raw material to the storage has a capacity of 600 t./hour. The conveyor bridge enters through the gable and is supported at every 6.0 m on beams suspended from the main frames. The off transport of the raw material from the storage is executed by means of an adjustable transverse cantilevered conveyor (see figure 4) which deposits the material on a conveyor mounted at floor level alongside the border of the storage area. The structural system applied for this storage seems to be adequate and economic and exhibits an outstanding example of introduction of light weight structural principles in a case where heavy dynamic loads from machinery and earthquake loads govern the design.

2. GENERAL LAY-OUT.

The plan lay-out of the hall is rectangular with a total length of 204 m and a width of 36.5 m necessary to make room for the storage area and also making room for the transport equipment travelling alongside the storage area. The module in the longitudinal direction for the primary structural planes is 6.0 m. The shape of the cross section of the hall is adapted to the functional requirements and the space demands for the transport and handling equipment of the raw material. The height of the hall is determined from the space demands to the conveyor bridge with an onloader arrangement working above the derrick type transporter positioned on the hall floor. The optimum cross section thus seems to be nearly A-shaped as shown on figure 4 with relatively low facade height of 7.6 m and a total height of 26.5 m above floor level to the top level of the symmetrical roof. The geometry and statical system of the primary structures in the module lines appears from figure 3 and 4. The facade and roof cover
Figure 3. Elevation of structural system.

Figure 4. Plan lay-out of limestone storage.

Figure 5. Cross section.
1. Asbestos cement plates. 2. C-200x2.5 mm. 3. RHS 180x180x6.3 mm
4. Pipe Ø 89x3.2 mm. 5. Conveyor bridge and deloader. 6. Traveling excavator.
Figure 6. Inside view of mounted hall structure.

Figure 7. Inside view. Travelling excavator in top position.
as well, consist of corrugated asbestos cement plates section No. B6. Daylight is achieved by means of transparent PVC plates fitting the corrugation of the asbestos cement plates and inserted in bands in the roof, in the facades and in the gables. The hall structure on the whole is separated by an expansion joint in two sections of equal length viz. 102 m. The spatial stability of both hall sections is established by means of latticework arranged between the frames in the roof planes and the facade planes. Further bracing systems are arranged inside the hall to obtain spatial stability of the transport bridge system.

3. DESIGN STANDARDS AND LOADING CONDITIONS.

All steel structures are designed and analysed in accordance with German standards. The climate loads however are estimated according to Indonesian standard to cope with the geographical location. The max. wind velocity pressure at the top of the hall structure is fixed to 1.10 kN/m² whereas the shape factors for the building follows DIN 1055. No snow load is considered whereas dust load according to usual practice for cement factories must be considered. Because of the steep 45° slope of the roof plane the dust load is assumed rather low to 0.5 kN/m². Besides these loads derived from the standards, miscellaneous loads from machinery and conveyer bridge supported on the hall structure are considered. The most dominating of these loads occur from the trolley on the bridge and additional inertia forces due to braking and impact.

The live load on the bridge is 7.20 kN/m distributed load and statical wheel loads from trolley totally 47 kN.

A special investigation has been made for earthquake loads corresponding to Indonesian standard. Earthquakes in this area have high intensity and Richter scale 8 is foreseen. Because of the high Richter intensity the influence from earthquake loads on stabilizing members will exceed the influence from wind load. As these loads shall not be considered simultaneously, obviously the earthquake will govern the design in respect of overall stability, whereas the wind load will govern the design of the individual lattice frames.

4. STRUCTURAL SYSTEM.

The structural system consists of primary structural planes in the module distance 6.0 m mutually interconnected by means of roof purlins and facade rafters in cold rolled C-shapes, 200 x 2.5 mm. In the third points of each roof plane and at the frame corners the C-shapes are replaced by RHS 180 x 180 x 6.3 mm. The roof purlins and the facade rails are at the centers intermediate supported on these rectangular hollow sections to reduce bending moments due to load tangential to the hall contour. The intermediate supports are established by means of round bars Ø20 mm joined with a sleeve jacket at every purlin and anchored sectionwise at the RHS-sections. The primary structures consist of statical determinate lattice frames with hinges arranged at the foundation level and at the frame top. Rather poor
Figure 8. Outside view of covered hall.

Figure 9. Conveyor bridge access through gable in the storage.
Figure 10. Frame corner and base hinge.
1. HEB 180. 2. HEB 180. 3. Pipe Ø89x4.0 mm. 4. Asbestos cement plates. 5. RHS 180x180x6.3 mm. 6. C-200x2.5 mm. 7. M36. Class 4.6. 8. Pl. 30x150x460 mm. 9. Cement mortar. 10. Ø6 mm self tapping screw. 11. Bar 30x30 mm. 12. Pipe Ø76x4.0 mm. 13. HEB 180. 14. Pl. 40x330x460 mm. 15. Pl. 40x300x460 mm.
Figure 11. Lattice frame legs.

Figure 12. Hinge connection at frame base.
foundation conditions make this system adequate as it is non-sensitive to differential settlements. The foundations of the frame legs are further reduced by introducing tension ties between the foundations below the concrete floor to resist horizontal thrust due to symmetrical vertical load. The lattice frames have variable height with a max. flange distance at the frame corners of 1.85 m decreasing to 0.75 m at the top and base. HE-sections are selected for both flanges. Optimum economy is obtained by orientation of the web of the outer HE-flange in plane with the frame to obtain max. rigidity of the beam columns spanning between the nodes. The inner flange is with the same aim however arranged with the web perpendicular to the frame to achieve max distance between lattice restraints necessary to prevent buckling out of plane. The latticework is V-shaped and pipes are throughout selected for the members with the exception of the member in the frame corner where a HE-section is more adequate. The bracing members are all welded directly to the flanges thus omitting gusset plates in the joints.

The variation in flange distance means that the member forces in the bracing are reduced considerably compared with member forces in a parallel flanged warren type truss. The rather low steel weight obtained in the present design is mainly a consequence of the above mentioned features and the application of cold rolled thin walled purlins and facade rails instead of ordinary rolled standard sections. The overall buckling length of the skew frame lattice girder is only 2.2 times the geometrical length due to adequate configuration with the relatively low facade height.

The conveyor bridge with trolley and deloader is build up of twin HEB sections in mutual distance 1740 mm interconnected with a V-shaped bracing in tubular members. The bridge girders are carried by a beam supported at one end on the frame and canti-levered beyond the other support, a vertical HEA section suspended from the top hinge connection joining the two frame parts. The spatial stability is achieved by means of k-bracing arranged in four modules between the suspenders to minimize the influence on the main frames from inertia forces. Expansion joint in the conveyor bridge is inserted just outside the gable through which the conveyor bridge continue down to ground level.

The gable columns are all rolled HE-sections simple supported at roof level and at foundation level. The section size varies corresponding with the height. The module distance between the gable columns is 6.08 m. The thin walled rafters are intermediate supported in a similar pattern as applied in the roof. The expansion joint separating the two hall sections has been arranged by means of sliding joints in all purlins and facade rails to avoid doubling of the lattice frames at the joint.
Figure 13. Detail of top hinge in lattice frame.
1. HEA 160. 2. Pipe Ø76x4.0 mm. 3. HEB 180. 4. HEB 160. 5. M42 Class 8.8. 6. Asbestos cement plates. 7. Asbestos flashing.
8. Timber 50x50 mm. 9. Pl. 30x100x160 mm. 10. Pl. 25x40x160 mm.
11. Pl. 10x200x225 mm. 12. Pl. 10x180x180 mm.
Figure 14. Centre hinge with suspender junction to lattice frame.

Figure 15. Welded frame corner.
5. OVERALL STABILITY.

The spatial stability of the two hall sections are achieved by means of lattice girders in the roof and facade planes with a total girder height equal to four modules of 6.0 m. The four-module lattice arrangement is chosen to reduce the additional load in the frame members and in the anchorage from wind load and earthquake load. The obvious advantage is that all frames could be designed equal.

Wind loads on the gables are transmitted through the main purlins in RHS sections to the nodes of the lattice system. A typical bracing is shown on figure 20. The top flanges of the lattice frames are tied to the rigid bracing system through the main purlins and the intermediate light weight C-purlins. Suction on the roof and horizontal load transverse to the hall direction develops compression in the bottom flanges of the frames. These flanges are therefore restrained against lateral buckling by means of pipe sections connecting the flanges at the frame corner and further adequate points shown on figure 3a to the roof bracing system.

Braking forces and earthquake forces on the conveyor bridge in the hall direction are transferred to the top nodes in the roof bracing system by a secondary k-bracing between the vertical suspenders over four modules of 6.0 m.

In the transverse direction of the hall the stability is established by frame action in the primary structure.

6. LATTICE FRAMES.

The selection of members for the lattice frames meet the requirements for both material economy and easy node performance. The V-shaped tubular bracing connecting the flanges of wide flange sections is chosen to obtain a repetitive node design and whence a possibility for a rational mass fabrication. The top flange is chosen as HEB 180 ... HE 160A because of the narrow spacing between the purlins and also for enabling a simple connection of the purlins to the flange. The bottom flange is also a HEB 180 ... HEB 160 section, however turned with the web perpendicular to the frame plan to achieve reasonable rigidity against out of plane buckling and thus minimizing the necessary number of restraints established by means of longitudinal bracing.

The relative small axial force in the lattice members achieved partially due to variation in the girder height, allow for a direct connection of the lattice members without gusset plates both at the top and bottom flange.

The top hinge between the two frame parts is a simple cylinder bearing with locks on both sides preventing vertical displacements. Separation is resisted by means of two M42 class 8.8 bolts in the hinge line, one on each side of the locks. The base plates for the hinge parts are elongated downwards to serve as seating for the gusset plate connection to the bottom flange and as bearing for the vertical suspenders HEB 160, which are part of the support system for the conveyor bridge. The bolted joint for the suspenders is a simple lap joint arranged with a center plate of 30 mm thickness matching the available gap be-
Figure 16. Bolted frame joint.
1. HEB 180. 2. HEA 160. 3. Pipe Ø89x4.0 mm.
4. HEB 160.

Figure 17. Bolted end plate joints in the lattice frame.
Figure 18. Main purlin details.
1. Pl. 20x160x340 mm. 2. Pl. 15x170x340 mm.
3. HEA 160, HEB 180. 4. RHS 180x180x6.3 mm.

Figure 19. Support of purlins.
1. RHS 180x180x6.3 mm. 2. C-200x2.5 mm. 3. Asbestos cement plates. 4. Rod Ø20 mm. 5. Pl. 10x100x280 mm.
tween the hinge base plates. Details of the hinge connection, node connections and miscellaneous other details in the frame structure are shown on figure 10-19.

The two hinges at the frame base are arranged with cylinder bearing on a bar welded to a 40 mm thick base plate distributing the load to the concrete foundation. A dowel shear lock is welded to the underside of the base plate. The 25° slope of the bearing plates relative to horizontal plane equals the slope of the reaction with the vertical direction due to dead load and half of the live load. Two anchorbolts M36 class 4.6 are placed in the bearing line, one on each side of the flange members. In this way the frame is rigid restrained perpendicular to the frame plane thus reducing the buckling length of the flanges. Shear displacements in the bearing plane is prevented by means of bar locks welded to the frame base around the bearing plate.

The transport joints are placed 7.0 m from the frame corner and executed as end plate joints in node centres in the bottom flanges and halfway between the nodes in the top flanges.

7. BRACING.

The bracing in the roof planes and the down lead latticework in the facade planes consist of crossing diagonals of single angle sections. The diagonals are kept free from the C-purlins by placing them below the gusset plates welded to the top flange of the frames. Strut members HEA 160 sections are introduced below the RHS main purlin sections to avoid eccentric loading and change in the cladding support system. All joints in the lattice system are bolted with bearing type bolts in oversize holes.

The bracing members for the bottom flange of the frame are pipes Ø89 x 3.2 mm connected to the main bracing system by means of k-bracing with pipe sections to the struts HE 160A. The bracing system for the conveyor bridge as well consist of k-bracing with pipe sections bolted to the nodes.

Thus the whole bracing system is built up of single straight members prepared for bolted connections to meet the requirements for easy handling and mounting.

8. ROOF AND FACADE CLADDING.

The roof and the facade to a level of 4.0 m above floor level is covered with corrugated asbestos cement plates in section B6. The cladding material is primarily chosen because of competitive price and because the plates are produced in Indonesia. The fastening of the asbestos cement plates to the thin walled steel sections were designed with self tapping stainless steel screws with neoprene washers. The corner flashings as well to be fastened with self tapping screws. The brittle nature of the asbestos cement plates call for special care when applying this rational fastening method instead of conventional hook bolts. The primary advantage of the self tapping screws compared with the hook bolts is that the former can be mounted of workers merely from the outside whereas hook bolts call for workers on both sides. However the fasteners were changed to ordinary hook bolts with neoprene washers by the contractor according to lo-
Figure 20. Overall view of roof latticework system.

Figure 21. Bolted joint in the roof latticework.
Figure 22. Part of main latticework and bracing of inner frame flanges.

Figure 23. Frame columns secondary bracing of interior flange.
The disadvantage of the asbestos cement cladding compared with an alternative corrugated steel sheet cladding is that an effective reliable diaphragm action cannot be established. As a consequence all the facade rails and roof purlins with a span of 6.0 m must have intermediate support. These are established by means of adjustable round bar ties ø20 fastened to every purlin and staggered 80 mm as shown on figure 19. At the expansion joint the gap between the asbestos cement plates is covered with a neoprene sheet glued to the plates.

9. STEEL GRADES.

Ordinary mild steel strength grade 37 according to DIN 17.100 has been used for all primary structures. However, the quality classes are varied according to detailing, welding technology and strength considerations especially regarding the risk of lamellar tearing and strength perpendicular to the rolling surfaces. For instance all end plates are supplied as killed steel RR St. 37.3. ultrasonic controlled to avoid the risk of lamination. Only special details as frame top hinge and base hinges and anchorbolts involve the application of steel grade 52, according to DIN 17.100. The thin walled cold rolled C-purlins are upgraded through the rolling procedure to a strength grade corresponding to 42 according to DIN 17.100. A general application of steel grade 52 for the primary structures would only result in a modest reduction in steel consumption because of the slenderness of the members in compression. The saving could hardly compensate for the higher unit price and the consequences of late delivery.

10. CORROSION PROTECTION.

All structural steel except thin walled purlins and anchorbolts were sandblasted to cleanliness grade Sa 2½ according to ASTM D2200-67 and received one shop primer coating on lead basis with thickness 15-20 microns before fabrication started. After fabrication the sections received an intermediate layer on lead basis with thickness 40 microns. After erection of the steel structure two further layers of alkyd-enamel was added reaching the demanded total layer thickness of 170 microns. The thin walled C-purlins and the facade rails are hot galvanized with a minimum zinc layer of 65 microns. The anchorbolts are galvanized similarly but only on the upper 350 mm. As painting after erection should be executed anyway all bolts are supplied black and lightly greased with oil. All bearing type bolts are prestressed partially with a torque of approximately 40% of the full moment adequate for friction type connections.
Figure 24. Support system for conveyor bridge. Bracing between suspenders.

Figure 25. Bolted joint in gable column.
Figure 26. View of the steel fabrication "shop" on the site.

Figure 27. Steel structure during erection.
11. FABRICATION.

The steel structure for the hall as other major steel structures for the whole cement plant were fabricated at a provisional arranged open air workshop near the building site by a local subcontractor. In this case special consideration has been aimed at a design easy to fabricate because of very limited automatic facilities in the shop setup. For instance no overhead traveling cranes were installed and all lifting and local transport took place by means of mobile jib cranes. Fabrication tools consisted of manual drilling machines, manual handled flame cutters and manual arc welding equipment. However no saws were available. Shortage on skilled labourers called for experienced Danish advisors in the field of welding and flame cutting technology to educate the employees of the local contractor. Shrinkage and residual stresses due to welding, usually calling for straightening in welded plate structures, are almost negligible with the present lattice frame system. All nodes joining pipe sections are designed with the aim of easy preparation of the pipe ends with plane cuts, allowing for merely application of fillet welds in the connections. The holes in the end plates for the bolted joints in the lattice frames were drilled together and connected to assure fitting before being welded to both flanges. The final adjustment of the frames took place during a pre-assembly on ground by means of shims in adequate thickness inserted between the end plate joints.

Even though the present applied open lattice system with repetitive node configuration enabled a rational flow in fabrication partly due to a rather moderate welding work per kg. steel. Straightening of members with initial imperfections were executed by means of local heating before assembly.

Tolerances.

As the whole structure is built up of welded elements in transportable lengths exclusively assembled with bolted erection joints it called for special attention on the accuracy of the shop fabrication to keep the tolerances within certain limits. For instance the final levelling of the conveyor bridge depends on the accuracy of the primary structural planes. Tolerances for the primary structure were:
- Inplantation and deviation in height of lattice frame bases: \( \pm 5 \text{ mm} \).
- Length of lattice frames: \( \pm 5 \text{ mm} \).
- Span of lattice frames: \( \pm 5 \text{ mm} \).

To ensure accuracy important for the final structure various precautions were taken in the design to enable adjustment of all primary connections. Thereby it was made possible to eliminate inevitable minor errors in manufacture and erection for instance error accumulation in the longitudinal direction of the hall.

a) Generally all bolted connections have been made as bearing type bolts in 1.0 - 1.5 mm oversize holes.
b) Application of end plate connections for primary roof purlins
Figure 28. Storage partly erected. Main purlin being lifted into position.

Figure 29. Steel structure with roof cover of asbestos cement plates before closing of gables.
allowing for filler plates of max 10 mm thickness.
c) Design details allowing for vertical adjustment of frame and
column bases, conveyor bridge girders and conveyor bridge
support system.

After erection a follow up check has been executed verifying
the positions of the primary structure to be within the sched-
duled tolerances. The trolley rail levels were adjusted within
± 5 mm and the rail distance within ± 3 mm. As no modifications
have been called for at any of the bolted connections during the
erection, this proves the adequate accuracy achieved during fa-
brication of the workshop elements.

12. TRANSPORT AND ERECTION.

Transportation of all members and welded lattice sections to the
erection site was easily handled by means of mobile cranes as
the fabrication area was nabour to the building site. The lat-
tice frame parts were assembled on the ground and each half part
of the three hinged frames were lifted in position by one mobi-
le crane with 30 m jib assisted by a smaller crane for the con-
trolling of the frame corner against tilting. The 25° slope of
the anchorbolts called for special concern because the frame
parts consequently had to be skew lowered approximately 150 mm.
After reaching contact in the base bearings the frame parts we-
re rotated around the base hinges until contact was obtained on
the top centre hinge. Provisional bracing with wire ties was
thereafter arranged and the procedure repeated with mounting of
the next frame. Erection started from one hall end which called
for a general temporary bracing until the modules with permanent
bracing were passed.

After adjustment of the main structure the support system for
the conveyor bridge was mounted and followed by the erection of
the 12.0 m long continuous conveyor beam sections, platforms and
staircases.

The cladding of asbestos cement sheets were mounted without scaf-
folding by workers climbing on the facade railings and roof pur-
lins, a procedure which in many industrialized countries would
be prohibited by civil law.

DESIGN AND CONSTRUCTION.

Main Contractor : The hall is part of a F.L. Smidth
turn-key delivery.
Construction : Waskita Karya, Indonesian subcon-
tractor.
Design : International Steel Consulting A/S
in collaboration with Danalith A/S
Copenhagen. Denmark.

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