

ERECTION TECHNIQUE OF SUPER-LONG SPAN DOUBLE-LAYER-LAYER SPACE GRID DOME

Field of Invention

The present invention relates to an erecting technique, specifically a long span double-layer space grid dome with the diameter of more than 100m which is able to magnificently reduce the steel consuming per square meter, and more particularly to a super-long span double-layer space grid dome erecting technique.

Related Art

With the rapid economic development of China in recent years, requirements of coal and other raw material in major industries as coal, electric power, cement, chemical, etc., has been increasingly growing, therefore triggered the massive development of the related storage facilities, referring to kinds of warehouses and dry coal sheds which are meant to play the environmental protecting and shielding roles. With the swelling extent of the colliery, power plants and cement factories, the spans and lengths of the coal sheds are consequently increasing, which demands more and more advanced designing techniques.

Space grid is one of the most ubiquitous and fast-growing space structures popular in different countries, widely used in various civil and industrial architectures. It's majorly applied in public buildings demanding long spans such as stadiums, airport terminals, hangars and conference centers as civil buildings, and kinds of warehouses, sheds, long-span plants and warehouse roofs as industrial constructions.

Space grid is a kind of 3D shaped structure with 3D load-carrying properties under loads. Space structure boasts the following features comparing to the planar structure: rationally loaded, lightly weighed, low cost, structurally diverse and super-span realizable, which make it the optimized load-carrying structural choice for various long-span storage sheds in major industries of coal, electric power, cement, and etc.

As a kind of curved surface grid structure, space grid has two forms of single layer and double layer. It boasts the following major features:

Grid structure shares major features in both bar system structure and shell system structure. In terms of load-carrying properties, the space grid structure uses similar grids to form spatial intersectional bar system, integrating the load-carrying structure and bearing structure, thus

effectively changed the stress state of the plane truss with majorly axial force which brings the properties of steel into full play. It's estimated that the average steel consumption of storage sheds using space grid structure with the span of over 60m is between 30 and 60kg/m², almost one half of that using portal frame or steel truss, which is between 60 and 12060kg/m². Furthermore, when the span crosses over 100m, solid-web portal frame is indeed impractical and the steel consumption of the steel truss structure will be more than 120kg/m².

According to the statistics, huge requirement of raw materials has been emerging due to the rapid industrial development in China, more than 50 spherical storage sheds with the diameter over 100m and more than 100 rectangular storage sheds with the monomer surface area over 20,000 square meters were erected every single year. Due to the considerably increased coal price in recent years, the multiple advantages of being able to reduce the loss of the coal and protect stackers in the building storage bunkers are commonly welcomed among mine owners. Therefore, there are constant and massive needs of developing new erecting structures that are not only low-cost, highly profited and environmentally friendly, but also with longer span and higher height in both old and new mining areas. The super-long span space grid dome has become one of the most popular erecting structures for the storage bunker, and extensively influenced all kinds of stocking buildings such as dry coal sheds in power industry and raw material warehouses in cement and steel industry. It's listed as an environmental protective project of new erecting storage domes in coal and cement industries, with the demands of designing, erecting and putting into use simultaneously with the major structures of the storage bunkers. It's estimated that this structure cannot be replaced by other structures such as intersecting truss or cable-membrane structure according to present structural development. But due to the influence from traditional designing and erecting concepts, the steel consumption of super-long span space grid doom with the diameter of over 100m is commonly around 120kg/m², which may cause direct burden to the cost and security problems to the space grid doom with such enormous deadweight.

In conclusion, the erection of super-diameter storage bunkers, especially those with super-long span dooms is developing into a trend, which promises bright prospects in the market, but the key to cutting cost and gaining competitiveness by remarkable margins relies on reducing the steel consumption from 120kg/m² to a rational level under the premise of safety guarantee.

SUMMARY OF THE INVENTION

The purpose of the present invention is for resolving the current problems of enormous steel consumption, high-cost raw material and complicated erecting process from building super-long span double-layer space grid domes, specifically, it's an erection technique of super-long span double-layer space grid dome with low steel consumption, convenient erecting method and safety guarantee.

The technical protocol of the present invention:

A super-long span double-layer space grid dome erecting technique, characterized in following steps:

Step 1, Determine the building dimensions depending on the storage volume and facilities to be installed, including height and diameter.

Step 2, Calculate the number of the grids then nodes based on the assumption of the length is 3 to 5 m per grid depending on the building dimensions.

Step 3, Put the local meteorological parameters into consideration, and input it with the number of grids and nodes into the parametric analysis software for wind tunnel test, to get the wind load distribution per grid.

Step 4, Input the wind load distribution per grid calculated from step 3 into the parametric analysis software with the constant load, the snow load and the earthquake load to get the maximum load of the nodes and their components on the whole dome.

Step 5, Choose members with appropriate sizes from the warehouse depending on the maximum load of different components.

Step 6, Recalculate and draw the working drawing depending on the recalculated sizes of the chosen members.

Step 7, Complete the concrete foundation according to the working drawing, then complete the whole erection of the dome with following measures:

1、Implement the erecting method of circle-by-circle closing along the diameter and layer-by-layer installation from bottom to top, with small-piece units prepared to form 2 or 3 triangles on the ground before high-altitude installation which could be consequently reduced.

2、Apply adjustable small gin pole hangers to realize lifting and installation of the small-piece units

3、Set safety piles around the doom area to compensate the wind influences with lassoes, the amount and position of safety lassoes should be altered with the increasing installation height of the building, and safety lassoes should be added on the windward side when the erecting height reaches 3/4 of the planning height.

4、Weld “L” steel in the purlin pallets of the grid, and complete the welding and drilling procedure of the “L” steel on the ground to realize direct binding of the purlin pallets and the bolts at high-altitude for accelerating the erection.

5、Use large-sized plates with the length of 8m~12m to install, and apply both manual pulling plates and adjustable small gin pole hangers to lift and install the plates to the installation working face.

The small-piece unit mentioned above is composed of two bolt balls and eight pieces of members

The height of bearing and the roundness of the closed circle should be controlled when the first circle in the circle-by-circle closing method is installed. The height of bearing should be adjusted by steel sheets with different thicknesses, and the roundness should be adjusted by the cross beam and the jack. The bearing should be welded and immobilized for the first time after repeated adjustment making sure the installation error is within the limits permitted by the specifications. Every circle should be checked when closed to guarantee the overall rigidity of the doom and keep errors from accumulating. Also the roundness and closing error of the overall installation project should be checked and adjusted when the installation of the second and third circles of the grids are completed to make sure all the indexes meet requirements of the specifications before the final welding and installation of the bearing. Afterward, the installation and closing should be carried out circle by circle, and the structural roundness should be checked and adjusted each time three circles get done using tension from the steel cables of anchor blocks.

Beneficial effects of the present invention:

1、Using wind tunnel simulation software to get wind force factors, and combined them with the unfavorable-load combination of data for setting up the calculating model. It replaced the wind tunnel experiment and became the new technique model for the advantages of less time consumption, lower cost and more accurate data.

2、Under the circumstance with no mature designing model, we integrated the calculating

models from finite element programs with other professional grid designing software in the way of comparing and cross checking, and successfully reduced steel consumption under the premise of structural safety (the steel consumption for 200,000t storage capacity is only 2460kg/m², lower than the amount for 100,000t or 50,000t storage capacity).

3、To ensure the structural safety, the present invention added extra erecting step in: running the simulator under the most unfavorable structure and maximum unfavorable wind load when the unclosed erection reached 3/4 of the planning height. This step provided proof to the erecting safety and feasibility of the erecting protocol by checking the calculated data.

4、The present invention implemented the erecting method of circle-by-circle closing and layer-by-layer installation from bottom to top, with small-piece units prepared on the ground to form 2 or 3 triangles to reduce high-altitude installation, then used vertical conveyor to hang them to the installation working face with unit-installing method instead of the full framing therefore reduced the cost and construction period.

5、The present invention solved the problem of the installation nodes were not at the same plane and the small-piece units must be angularly regulated before transporting to the installation place by using adjustable small gin pole hangers.

6、The present invention pointed out for the first time that during the high altitude unit-installation, under the influence of the deadweight and wind load, the space structure system cannot be formed and the structure faced the most unfavorable situation at 3/4 of the planning height (above 50m), especially when the wind level was above 8. Thus the safety lassoes were applied toward the wind under the unfavorable structure and wind load, which eventually produced satisfying result by determining the amount and positions of safety lassoes according to the confirmatory calculation and altering them with increasing installation height of the structure.

7、The present invention resolved the problem that the former purlins were connected by welding at high altitude so the control of welding quality was limited, and the consumption of welders, handle lines and power lines was so enormous that it was not only inefficient but unsecure. In the present invention, “L” steel was welded in the purlin pallets of the grid, and the welding and drilling procedures were done on the ground to realize direct binding of the purlin pallets and the bolts at high-altitude so the construction period was shortened and the quality and safety was also guaranteed.

8、The present invention used 8m~12m for average length of an installing unit for reducing seams, and commonly used manual drawplates hanging to the installation working face, but under circumstance that the height was above 50m and the wind was strong, adjustable-gin-pole hanging and wind-rope controlling were also applied with manual drawing to ensure safety and reliability of the erecting method.

9、The present invention was able to extent the span, height and storage capacity of the doom to a brand-new level, which offered the owners more options to fully use the space and laid a solid foundation for further development of super-long span technology.

10、The present invention provided the owners increased using space and reduced costs. For instance, the steel consumption for 100,000t storage capacity is 29.6 kg/m² with the price of 10.61 million while for 200,000t storage capacity is 24 kg/m² with the price of 7.92 million. We may notice the price and cost was reduced, which not only laid a solid foundation for its promotion but also guaranteed the profit for the company.

11、The present invention laid a solid foundation to prove the structural safety and reliability, as well as guaranteed the construction period, quality and safety of the long span storage bunkers.

12、The present invention replaces the wind tunnel experiment for the whole spherical structure with the wind load of the grid calculated by the simulator, remarkably enhanced the accuracy of the experiment in replacing the overall structure model with the node-based model which reflected the load-carrying state of the nodes more precisely and consequently enjoyed higher accuracy. Besides, it regulated the sizes of the grids according to changes of the load on different layers from top to bottom, which proved the calculating method of the present invention was more scientifically rational because the calculated steel consumption per square meter not only guaranteed the structural rigidity but also saved the steel consumption by the greatest margin. The steel consumption of long span doom using the present invention for a storage bunker of 200,000t capacity using the present invention roughly equaled that using traditional erection technique for 100,000t storage capacity. The cost was reduced by 30% merely considering the aspect of steel consumption.

13、The present invention calculated the optimized steel consumption per unit area with different wind loads under circumstances meeting national standards after repeated experiments, as showed in the following tablet.

No.	codes				load				Economic indicators	
	Inner Diameter (m)	Height (m)	Thickness Of Grid (m)	Surface Area m ²	Constant Loadk (N/m ²)	Variable loadk (N/m ²)	Dust Load (kN/m ²)	Fundamental Wind Pressure (kN/m ²)	Steel Consumption Of The Major Structure (t)	Steel Consumption Per Square Meter(kg/m ²)
1	100	42	2.00	14036.64	0.25	0.5	0.5	0.35	263	18.74
								0.50	267	19.02
								0.65	275	19.59
								0.80	280	19.95
								1.00	330	23.51
2	110	46	2.20	16926.40	0.25	0.5	0.5	0.35	316	18.67
								0.5	324	19.14
								0.65	335	19.79
								0.80	347	20.50
								1.00	380	22.45
3	120	50	2.50	20125.83	0.25	0.5	0.5	0.35	390	19.38
								0.50	408	20.27
								0.65	426	21.17
								0.80	437	21.71
								1.00	475	23.60
4	130	55	3.00	24030.04	0.25	0.5	0.5	0.35	540	22.47
								0.50	558	23.22
								0.65	576	23.97
								0.80	606	25.22
								1.00	685	28.51

14、The present invention creatively replaced the traditional wind tunnel modeling experiment with the wind tunnel simulation test of the grid integrated with parametric analysis, which may reduce the construction period by more than 50% and remarkably cut the constructional design cost of the major structures and consequently cut the project cost. The cost for a storage bunker of 200,000t capacity using the present invention roughly equaled that using traditional erection technique for 100,000t storage capacity, and the effect of energy saving was also preferable.

Brief description of drawings

Figure 1 is the shape factor view of Embodiment 1 for the present invention.

Detailed description of the embodiments

The details of the present invention are further described with drawings and embodiments as below.

As showed in Figure 1.

A super-long span double-layer space grid dome erecting technique, characterized in following steps:

Step 1, Determine the building dimensions depending on the storage volume and facilities to be installed, including height and diameter.

Step 2, Calculate the number of the grids then the number of nodes based on the assumption of 3 to 5 m in length per grid depending on the building dimensions.

Step 3, Put the local meteorological parameters into consideration, and input it with the number of grids and nodes into the parametric analysis software (such as SFCAD by Beijing Yunguang Design and Consulting Office, 3D3S by Tonglei Civil Engineering Technology Co., Ltd. Shanghai Tongji University, Mudagen by MIDAS IT, Korea, and TWCAD by Institute of Structural Engineering, Shanghai Jiaotong University) for wind tunnel test, to get the wind load distribution per grid.

Step 4, Input the wind load distribution per grid calculated from step 3 into the parametric analysis software with the constant load, the snow load and the earthquake load to get the maximum load of the nodes and their components on the whole dome.

Step 5, Choose members with appropriate sizes from the warehouse depending on the maximum load of different components.

The same parameter can be put into different software for cross check in practice, referring to repeat step 1 to step 5 for 1 to 3 times, and base the designing on the maximum size of members calculated.

Step 6, Recalculate and draw the working drawing depending on the recalculated sizes of the chosen members.

Step 7, Complete the concrete foundation according to the working drawing, then complete the whole erection of the dome with following measures:

1. Implement the erecting method of circle-by-circle closing and layer-by-layer installation

from bottom to top, with small-piece units prepared on the ground to form 2 or 3 triangles before high-altitude installation which could be consequently reduced. the height of bearing and the roundness of the closed circle should be controlled when the first circle in the circle-by-circle closing method is installed. The height of bearing should be adjusted by steel sheets with different thicknesses, and the roundness should be adjusted by the cross beam and the jack. The bearing should be welded and immobilized for the first time after repeated adjustment making sure the installation error is within the limits permitted by the specifications. Every circle should be checked when closed to guarantee the overall rigidity of the doom and keep errors from accumulating. Also the roundness and closing error of the overall installation project should be checked and adjusted when the installation of the second and third circles of the grids are completed to make sure all the indexes meet requirements of the specifications before the final welding and installation of the bearing. Afterward, the installation and closing should be carried out circle by circle, and the structural roundness should be checked and adjusted each time three circles get done using steel cables from anchor blocks.

2. Apply adjustable small gin pole hangers (can be realized with the practical and new patent which the applicant has filed an earlier application, namely Patent Application No. 200820186176) to realize lifting and installation of the small-piece units.

3. Set safety lasso piles around the doom area to compensate the wind influences with lassoes, the amount and position of safety lassoes should be altered with the increasing installation height, and safety lassoes should be added on the windward side when the erecting height reaches 3/4 of the planning height.

4. Weld “L” steel in the purlin pallets of the grid, and complete the welding and drilling procedure of the “L” steel on the ground to realize direct binding of the purlin pallets and the bolts at high-altitude for accelerating the erection.

5. Use large-sized plates (could be color steel plates) with the length of 8m~12m to install, and apply both manual pulling plates and adjustable small gin pole hangers to lift and install the plates to the installation working face.

Control of following items should be emphasized during the erecting process:

1、The installation accuracy should be under control. The requirement of the installation accuracy of the grid is extremely restrict, installation errors that cannot be neglected will directly influence the installation speed and the structural safety in forming great stress inside

the structure. We focused on the following two aspects in controlling the installation accuracy and keeping errors from accumulating: Firstly, install the first circle, including controlling the height of bearing and the roundness of the closed circle. The height of bearing should be adjusted by steel sheets with different thicknesses, and the roundness should be adjusted by the cross beam and the jack. The bearing should be welded and immobilized for the first time after repeated adjustment making sure the installation error is within the limits permitted by the code. Secondly, every circle should be checked when closed to guarantee the overall rigidity of the doom and keep errors from accumulating. Also the roundness and closing error of the overall installation project should be checked and adjusted when the installation of the second and third circles of the grids are completed to make sure all the indicators meet requirements of the codes before the final welding and installation of the bearing. Afterward, the installation and closing should be carried out circle by circle, and the structural roundness should be checked and adjusted each time three circles get done using tension from steel cables of anchor blocks.

2、 Small hangers should be applied. When the installation height is higher than 30m, the derrick truck will greatly increase the installation cost and slow down the installation process, and is completely impractical above the height of 50m, so there was no other way but to carry out research and development of small attached hangers. Due to the changing angle of inclination of the grid according to the increasing height and differences between upper and lower cambers, 6 different forms of small hangers need to be developed in total to meet the installation requirement of different parts of the construction. The small hanger for which the applicant has filed a practical and new invention patent application boasts the features of light-weighted, flexible, accurate-positioning and high efficient for installation, which may highly improve the installation accuracy and speed.

3、 The structural safety under strong wind should be guaranteed. The grid structure faced the most unfavorable situation at 3/4 of the planning height (or above 45m), especially when the wind level was above 5, so groups of anchors (20 groups or more) were set up on the sandy ground around the doom tensioned by steel cables for the safety consideration. Favorable results turned out from the experience that it not only effectively compensated the wind load but also restrained the whole structure from deformation so the doom could be successfully closed.

4、 The plates (could be color steel plates) should be installed on windy circumstance under certain methods. Large plates with average lengths of 8m to 12m were applied in the present

invention to reduce the amount of joints, improve the wind-resist function and make the whole construction look better. It was hard to immobilize the veneers under wind influence which may cause accidents putting the rarely wind-free weather into consideration. To solve this problem, the erecting techniques of bottom-to-top and windward-to-leeward installation with wind ropes were applied to guarantee the normal installation under common wind influences so the constructions can be put into operation on time.

The material conservation principle of the present invention was further described with the following design and calculation from an instance of erecting a storage bunker.

The spherical grid structure boasts the optimized load-carrying property which enables the realization of super-long span. The structural choice for the storage bunker should primarily meet the pragmatic function of providing enough space for coal storage facilities such as the material piling and taking machines, buckets, gantry cranes, conveyors and etc. Spherical grid structure could be applied for circular material piling and taking machines, and cylindrical grid structure could be applied for rectangular material piling and taking machines (bucket), gantry cranes and conveyors, and put factors as span, stiffness requirements, planar shape, bearing conditions, installation indicators, and technical and economic indicators into consideration comprehensively under this premise to determine specific parameters.

Double-layer grid structure may use articulated joints, while single grid structure should use rigid joints.

The planar dimensions, vector height and thickness of the double-layer grid should be restrained for rational stress state and favorable rigidity of the grid structure. The aspect ratio should be larger than 1, the span ratio should be between $1/6$ and $1/2$, and the shell thickness should be between $1/50$ and $1/20$ of the span for the double-layer-layer cylindrical grid. The span ratio should be less than $1/2$, and the shell thickness should be between $1/50$ and $1/20$ of the span for the double-layer-layer spherical grid. For instance, double-layer-layer spherical grid with the diameter of 100m should control the vector height below 50m and the thickness between 1.75m and 3.3m. Thickness of 2m to 2.5m under common load-carrying situation is economically favorable. The shell thickness of the Huolinhe storage bunker using spherical grid structure with a span of 133m is only 2m.

The grid structure commonly produces fairly large horizontal thrust.

For the cylindrical grid, its horizontal thrust is proportional to its vertical load which could

reach 100-400KN, so inclined pile or foundation is commonly applied for enough load-carrying capacity.

The horizontal thrust produced by spherical grid structure could be offset in two ways: immobilize the shell structure by members from itself, or immobilize the ring beams of the lower structure by enough steel. The horizontal thrust exerting on the foundation would be fairly small, merely around 10KN under the circumstance above. The calculated maximum displacement of the grid structure should not be larger than 1/400, and the deflection not be larger than 1/250, of the end span.

Loads and their effects of the grid structure of storage bunkers

Major loads of the grid structure are constant loads, variable loads (live load, snow load, wind load and dust load) and effects (temperature effect, seismic action)

Constant loads, commonly include dead weight of the grid structure and the roof enclosing structure, loads of hanging facility tubes (tubes, spray systems), and the bridgeway load.

In various storage bunker structures, the average deadweight of the grid structure was 0.2-0.4KN/m², and that of the roof enclosing structures including purlin plates and color steel plates is 0.15-0.2 KN/m². So the average constant load may reach 0.35-0.6KN/m² under circumstances without facilities or bridgeway loads.

Variable loads of the storage bunkers have mainly four forms: roof live load, dust load, snow load, and wind load.

Roof live loads should be determined according to the codes from “Load codes for the design of building structures” (GB5009-2001) during which the average unmanned roof live load is 0.5KN/m². It should be determined according to related codes when it's foreign project carrying out, and the value is around 0.57KN/m² according to the codes of India or the US.

The dust load must be put into consideration in industries such as building material and metallurgy industries, and the value is commonly 0.5KN/m² or 1.0KN/m² among different countries (specifically determined by the situation of material storage and dust sources around). It can be neglected in power of coal industries for fairly favorable operating environments. And the dust load should be considered with the greater value from the snow load and the roof live load simultaneously.

The snow load is one of the key loads for the grid structure of storage bunkers, and is a sensitive figure to long-span structures. The collapse of the grid structure occurred more than

once in different countries due to heavy snow (uneven snow loads). The snow load must be put into consideration in areas with snowing possibilities, and the situation can be specifically divided into three kinds of even, uneven and half-even distribution. Major factors that influence the distribution on the roof having snow load are wind, inclination and roof shape. The uneven snow load distribution is usually dominating for grid structures. The snow load should be considered with the dust load but not the live load in combination according to the codes in China. The basic snow load values could be found in the codes.

The wind load is also one of the key loads for the grid structures, and usually the dominating load for long-span structures. The wind acting on the grid structures could be simplified to the equivalent static load, with its direction vertical to the building, and its standard values can be calculated from the following formula:

$$W_k = \beta \mu Z \mu_s W_0 \quad (5-1)$$

W₀: Basic wind load

μ_s: Wind load shape factor

μ_Z: Wind load height variation factor;

β: Wind vibration factor.

$$W_0 = 0.5 \rho v^2 \quad (5-2)$$

W₀: Basic wind load

ρ: Air density (1.25kg/m³)

v: Average wind speed tested at the height of 10m in 10min

All the factors above can be found in domestic load codes.

The wind loads calculated from codes of different countries are significantly different, which mainly due to the following reasons.

Basic wind speed

The significant difference in basic wind load leads to similar difference in basic wind speed, which is because different time intervals (interval in short) were used in determining the basic wind speed. Because the wind is naturally in pulse state (with the predominant period of about 1min), it shows the result that the longer the intervals, the lower the average wind speed. The relations between the wind speed and the intervals are as below.

Wind Speed Interval	1h	10min	5min	2min	1min	0.5min	20sec	10sec	5sec	Instant
Statistical Ratio	0.94	1	1.07	1.16	1.20	1.26	1.28	1.35	1.39	1.50

Common choices for wind speeds of different countries are 10min wind speed and 3sec wind speed. China, Japan, former Soviet Union countries and ISO International Standards Association are using 10min wind speed, while the US, India, UK and Commonwealth countries are using 3sec wind speed. In meantime, the return period may also influence the wind speed, and it's 50 years the common choice for the majority of countries in designing common structures. In Japan, it's 100 years.

Basic wind speed fixed parameters, including wind pressure altitude factor and terrain classification.

The topography is classified into four forms as A, B, C, D in the Chinese codes, equaling D, C, B, A in the US codes. The Indian codes are more detailed, with three subclasses under each class, and their 1A, 2A, 3C, 4C equal A,B,C,D in the Chinese codes, but differ greatly in altitude factors with different topographies. Details are in the following tablet:

Wind pressure altitude coefficient in Chinese codes							
Ground Roughness Type	Height from the ground (m)						
	10	15	20	30	50	100	150
A	1.38	1.52	1.63	1.8	2.03	2.4	2.64
B	1	1.14	1.25	1.42	1.67	2.09	2.38
C	0.74	0.74	0.84	1	1.25	1.7	2.03
D	0.62	0.62	0.62	0.62	0.84	1.27	1.61

Velocity pressure exposure coefficient in US codes							
Ground Roughness Type	Height from the ground (m)						
	10	15	20	30	50	100	150
D	1.18	1.27	1.33	1.43	1.56	1.76	1.88
C	1	1.09	1.11	1.26	1.41	1.61	1.76
B	0.72	0.81	0.88	0.99	1.14	1.38	1.55

A	0.43	0.52	0.57	0.68	0.83	1.1	1.28
Wind speed altitude coefficient in Indian codes							
Ground Roughness Type	Height from the ground (m)						
	10	15	20	30	50	100	150
1A	1.05	1.09	1.12	1.15	1.2	1.26	1.3
2A	1	1.05	1.07	1.12	1.17	1.24	1.28
3C	0.82	0.87	0.91	0.96	1.02	1.1	1.15
4C	0.67	0.67	0.67	0.83	0.95	1.05	1.1

It can be learned from the tablet above that the altitude factors from Chinese, US and Indian codes fluctuated in quite a range. We ran a comparison of the three and the differences were showed as below:

	High Coefficient						
Ground Roughness Type	Height from the ground (m)						
	10	15	20	30	50	100	150
Chinese Code A	1	1	1	1	1	1	1
US Code D	1.17	1.20	1.23	1.26	1.30	1.36	1.40
Indian Code 1A	1.31	1.39	1.46	1.57	1.69	1.90	2.03
US / Indian Code	1.12	1.17	1.19	1.24	1.30	1.40	1.45

	High Coefficient						
Ground Roughness Type	Height from the ground (m)						
	10	15	20	30	50	100	150
Chinese Code B	1	1	1	1	1	1	1
US Code C	1.00	1.05	1.13	1.13	1.18	1.30	1.35
Indian Code 2A	1	1.09	1.17	1.27	1.43	1.69	1.86
US / Indian Code	1.00	1.04	1.04	1.13	1.21	1.30	1.38

	High Coefficient						
Ground Roughness Type	Height from the ground (m)						
	10	15	20	30	50	100	150
Chinese Code C	1	1	1	1	1	1	1
US Code B	1.00	1.00	1.00	1.00	1.10	1.23	1.31
Indian Code 3C	0.90	0.85	0.92	1.04	1.23	1.55	1.77
US / Indian Code	0.90	0.85	0.92	1.04	1.12	1.25	1.35

It can be learned from the tablet showing factors in three types of common topographies above that the factors from Chinese codes are larger than those from US and Indian codes, and the disparity tends to increase with the altitude enhancing.

Wind vibration factor

Due to the long span of the grid structure, the natural vibration period is larger than 0.25s. The wind vibration factor can be calculated from professional software as SRSS or CQC. The accuracy with CQC is higher but more time consuming, while that with SRSS is accurate enough for grid structure. The maximum wind vibration factor for a spherical storage bunker with a diameter of above 80m is between 1.4 and 1.6. It's changing with the altitude enhancing: the higher the altitude, the larger the factor, showing an inverted pot-bottom shape. The value to long cylindrical storage bunkers with the span from 40m to 60m is roughly 1.3 to 1.4, and roughly 1.4 to 1.6 with the span from 60m to 80m.

Shape factor and Wind tunnel test

Shape factors of most architectural forms were provided in Chinese load codes, so the factors for common storage bunker structures such as closed hemispherical type and double-layer-groove type can both be found. For foreign projects, it should be determined integrated with factors from related codes. For the common storage bunker space grid structure of landed arches, there're differences among the three countries, the factors from US codes roughly equaled those from Indian codes, both larger than those from Chinese codes.

Ground Roughness Type	Shape Coefficient					
	Ration of rise to span 0.5			Ration of rise to span 0.3		
	Front	Top	Back	Front	Top	Back
Chinese Code	0.6	-0.8	-0.5	0.33	-0.8	-0.5
US Code	0.71	-1.20	-0.50	0.42	-1.00	-0.50
Indian Code	0.70	-1.20	-0.40	0.40	-1.00	-0.40

For some complicated, long-span and especially crucial storage bunker structures, specific shape factor may not be covered by those in the codes. Because the shape factors from the codes didn't reflect the influences from surroundings, atmospheric boundary layer and 3D air flow, the structural wind load calculated according to the codes are generally conservative and partially insecure. So the wind tunnel simulation test is definitely necessary for a better wind-resistant

designing. Generally speaking, the purpose of the wind tunnel test is to simulate the wind load acted on the building at the atmospheric boundary layer with the influence of the adjacent buildings, ground roughness and wind directions, and get the wind load distributions on the surface of the building using rigid model pressure data, in order to offer solid foundation for rational determinations on wind load for the spherical shell structure of the storage bunker.

The wind tunnel test requires wind tunnel facilities and physical model of the buildings. However, the wind tunnel facilities are rare in China which could only be found in a couple of nuclear research institutes of several universities such as HIT, Tongji University, Tsinghua University and Tianjin University, and the test was quite cost and time consuming. We started the application of computational wind tunnel simulation analysis introduced by HIT, just to find the results produced from the software shared satisfying consistency with the data from physical model, so it's not only feasibly but also significantly cost and time saving. The average time for wind tunnel simulation using software is about one week, only 1/4 of that using physical models, and the cost can be controlled within ¥200,000, only 1/3 to 1/2 of that using physical models. There are several accessible options to realize these functions, such as CFD Wind Tunnel System, Digital Wind Tunnel (DWT) Wind Tunnel Simulator, and ANSYS 2D Wind Tunnel Test Simulator. These software feature in different ways, and should be simultaneously applied if accessible.

The following consequences are based on the wind tunnel simulation tests for two storage bunkers with respective capacities of 100,000t and 200,000t, and spans of 133m and 130m, as well as two spherical storage bunkers with the common span of 120m.

1) The wind loaded on the shell surface was majorly acting as an attracting effect, except on the small part in front which showed pressing effect, and the closer to the top of the shell, the stronger the wind attracting effect showed, which reached its max on both sides windward at the shell hat due to the divergence of the air at the shell hat.

2) The wind load showed a paralleled distribution while vertical to the airflow direction, which meant the wind load factors were close to each other on different sections vertical to the airflow direction.

3) For storage bunkers of spherical grid structure, the testing results were similar with the factors from the codes, which could be applied under circumstance without significant interference. Otherwise, the wind tunnel simulation tests should be run.

In conclusion, as a complicated and dominant factor in designing the spherical grid structure for storage bunkers, the wind load should be highly valued. The application of wind tunnel simulation technology could magnificently save time and cost, and the factors from the codes could be applied under circumstance without significant interference around the spherical grid structure. Due to the differences between wind loads calculated according to codes of different countries are not neglectable, the parameters should be appropriately transferred from different code systems to fit a uniform standard for avoiding security problems. For instance, 3sec wind speed should be transferred into 10min wind speed if the overall structure is designed under Chinese codes, similarly 10min wind speed should be transferred into 3sec wind speed under the US codes. Varieties in certain parameters of even calculating results may not necessarily mean unsecure or conservative, because all the codes from different countries are self-contained. It's crucial to consider the comprehensive effect, and their roles in the overall structural calculating system.

Temperature effect

The grid structure is a super static structure, so the members are not retractile under uniform temperature changes, and causes stress which we called temperature stress. So temperature effects should be put into consideration with long-span grid under significant environment temperature difference, by long-span, we meant a diameter over 60m for the storage bunker of spherical grid structure, or a span over 40m for the storage bunker of cylindrical grid structure. The temperature difference is commonly determined by the difference between the temperature when the erecting installation finished (bearing immobilized) and the local highest or lowest temperature.

According to the calculating result, the temperature effect is linearly proportional to the temperature difference, and exponentially proportional to the vertical stiffness.

Members using in storage bunkers of spherical grid structure have respective directions, so the temperature effect has little influence to the lower structure. In the 200,000t project at Huolinhe, due to different thermal expansion factors of the 18m-high concrete wall and the steel spherical grid used in the lower structure of the storage bunker, the temperature effect would not be neglectable using common plate bearing, so we replaced them with rubber bearing to release the temperature effect.

Seismic action

In areas with the earthquake intensity 7, vertical seismic design could be omitted but not the horizontal seismic check, and both should be done at the intensity 8 or 9.

Mode decomposition method could be applied in considering the seismic action to the grid structure, which should be complemented with time history analysis in designing complicatedly shaped or heavy grid structures.

The influence from the bearing structure to the grid structure has been put into consideration when the seismic analysis was done.

The seismic action to storage bunkers with cylindrical grid structure is commonly significant in the central area and insignificant in both sides and at 1/3 of the longitude. The horizontal seismic action increases with the span ratio increasing, and the vertical seismic action slightly decrease with the span ratio increasing. Increase in the shell thickness will lead to the increase in rigidity, and thus to the increase in seismic action.

Seismic action factor is significant on circular and diagonal members and insignificant on other parts. The horizontal seismic action increases with the span ratio increasing, and the vertical seismic action slightly decrease with the span ratio increasing. Increase in the shell thickness will lead to the increase in rigidity, and thus to the increase in seismic action.

Protection measures in designing storage bunkers

Antirust measures

Serious antirust measures should be taken for maintaining major structures of the storage bunkers. Rust should be firstly removed thoroughly from the steel members, making them meet the standard of Sa2.5 at least. Shot blasting and armament process are possible options, and the latter boasts the best effect but expensive while the former is affordable and similarly practical. Secondly, the steel members should be protected with fine antirust layers using hot galvanizing, hot aluminizing or non-metallic coatings. For the first two, the thickness of the layers should be thicker than 80um, for non-metallic coating materials, zinc rich epoxy, polyurethane and CSM are quite feasible and the thickness of the layers should be thicker than 125um. Zinc rich epoxy primer and polyurethane finish were used in the 200,000t project and satisfying result was received. CSM finish was used in Zhongyuan Dahua project for the local chemical and

atmospheric conditions, and zinc spray plus zinc rich epoxy primer was used in the Ninghai power plant project for its ocean atmosphere conditions. The total thickness of the intermediate coat and the polyurethane finish is more than 200um, and its antirust period is expected to reach 50 years.

Fire prevention

Three measures could be applied:

1. Fire preventing paint. It enables the refractory time of the steel members to reach 2 hours.
2. Sprinkler system.
3. Quarantine system. The designing distance between the coal piles and the steel members should be more than 3m, keeping the fire from spontaneous combustion of the coal piles from the steel members.

Measures against lateral pressure

Following measures could be applied:

1. Set up inner walls to retain the coal.
2. Enlarge the structural span properly, to keep secure distances from coal piles.
3. Set the bearing high to avoid the coal piles.

Wind tunnel simulation calculation was applied in building some 100,000t and 200,000t storage capacity projects, which shortened designing time and saved designing cost.

Take the doom of certain open coal power plant for instance. The major function of the doom is to protect the coal piles at the lower part of the storage bunker and keep the stackers from adverse influences of wind, rain and snow. Concrete silo was built according to the technique requirements, with the height of 18.5m, inner diameter of 120m and maximum overall diameter of 130m, for functions of enhancing coal piling height and resisting lateral pressure to increase storage capacity. In the meantime, double-layer space grid structure was applied for the upper part, with the span of 122.6m, height of 47m and surface area of 19,000 m², enclosing with purlin plates and single-layer color steel plates, and glass fibers were set at certain parts to enhance the day-lighting band of resin boards.

Design Parameters:

- 1、 Structure Type: double-layer-layer spherical steel grid
- 2、 Design Dimensions: span = 122.6m, vector height = 47m
- 3、 Grid Type: square pyramid
- 4、 Grid size: 3.73m in radial direction, 2.0~3.8m in circumferential direction
- 5、 Node Types: bolt ball
- 6、 Bearing Arrangement: one peripheral bearing was set every 10 degrees, 36 in total
- 7、 Bearing Types: laminated rubber bearing

Design Loads:

- 1、 Constant Load: 0.45KN/m^2
- 2、 Live Load: 0.5 KN/m^2
- 3、 Additional Load: 0.15 KN/m^2
- 4、 Basic Wind Load: 0.65 KN/m^2
- 5、 Basic Snow Load: 0.3 KN/m^2
- 6、 Earthquake Intensity: 7 Basic Seismic Acceleration: 0.10
- 7、 Temperature Effect: +35, -40。

Member size: $\phi 60 \times 3.5$, $\phi 75.5 \times 3.75$, $\phi 88.5 \times 4$, $\phi 114 \times 4$, $\phi 140 \times 4$, $\phi 159 \times 6$ (8), $\phi 180 \times 10$,

Material: Q235 (welded pipe) or 20#steel (seamless pipe)

Bolt ball size: $\phi 100$, 120, 150, 180, 200, Material: 45#steel

Cone, seal board material: Q235

High-strength bolts: 10.9 or 8.8

Control Indexes:

- 1、 Member slenderness ratio: strut bar ≤ 150 tie rod ≤ 250
- 2、 Displacement: $\leq 1/400$
- 3、 Stress ration: $\leq 195\text{N/mm}^2$

Load Input:

Choose Version SFCAD2000 or MTS2006 in using the software, so the models could be generated automatically or by transferring the cylindrical shell. The wind load shape factors were mainly taken from the codes, complemented by the wind tunnel simulation values. Figure 1 is the result figure of the wind tunnel experiment shape factors.

The shape factors formula given by the code is as below:

$$\mu_s = 0.5 \sin^2 \varphi \sin \varphi - \cos^2 \varphi$$

φ : angle between the normal and the vertical

φ : horizontal angle

Following conclusions are drawn from calculations and comparisons.

1、The factors from the wind tunnel simulation are roughly the same with the standard factors on the side facing the positive pressure.

2、The factors from the wind tunnel simulation on the lee of the top cap are relatively disordered, a few are larger than the factors from the codes, but under comprehensive comparison, they are slightly smaller than the standard factors in general.

3、The factors from the wind tunnel simulation on the lee side facing the negative pressure with a normal angle above 30° drop quickly, and significantly smaller than the standard factors.

4、The standard factors are totally acceptable for single spherical dome with no obstacles or interferences. If there's interference source, the wind tunnel simulation should be run for more precise shape factors.

Wind-induced vibration factors could be calculated by SRSS. Consistent displacement wind-induced vibration factor is 1.557, and consistent internal force wind-induced vibration factor is 1.330.

Calculation Combinations.

Combinations are as below:

(1) 1.20constant

(2) 1.20constant+1.40live1

(3) 1.20constant+1.40live2

(4)~(11) 1.00constant+1.40wind1~8

(12)~(19) 1.20constant+1.40live1+0.84wind1~8

(20)~(27) 1.20constant+1.40live2+0.84wind1~8

(28) 1.20constant+1.40temperature (+35)

(29) 1.20constant+1.40live1+1.40temperature (+35)

(30) 1.20constant+1.40live2+1.40temperature (+35)

(31) 1.20constant+1.40temperature (-40)

(32) 1.20constant+1.40live1+1.40temperature (-40)

(33) $1.20\text{constant} + 1.40\text{live}_2 + 1.40\text{temperature}$ (-40)

(34) $1.20\text{constant} + 1.30\text{seismic}$

(35) $1.20\text{constant} + 0.60\text{live}_1 + 1.30\text{ seismic}$

(36) $1.20\text{constant} + 0.60\text{live}_2 + 1.30\text{ seismic}$

(37) $1.20\text{constant} + 1.40\text{live}_1 + 0.98\text{live}_2$

Other sections in the present invention which were not mentioned are similar to the existing technologies or could be realized by the existing technologies.

CLAIMS

1. A super-long span double-layer space grid dome erecting technique, characterized in following steps:

Step 1, Determine the building dimensions depending on the storage volume and facilities to be installed, including height and diameter.

Step 2, Calculate the number of the grids then nodes based on the assumption of the length is 3 to 5 m per grid depending on the building dimensions.

Step 3, Put the local meteorological parameters into consideration, and input it with the number of grids and nodes into the parametric analysis software for wind tunnel test, to get the wind load distribution per grid.

Step 4, Input the wind load distribution per grid calculated from step 3 into the parametric analysis software with the constant load, the snow load and the earthquake load to get the maximum load of the nodes and their components on the whole dome.

Step 5, Choose members with appropriate sizes from the warehouse depending on the maximum load of different components.

Step 6, Recalculate and draw the working drawing depending on the recalculated sizes of the chosen members.

Step 7, Complete the concrete foundation according to the working drawing, then complete the whole erection of the dome with following measures:

1. Implement the erecting method of circle-by-circle closing along the diameter and layer-by-layer installation from bottom to top, with small-piece units prepared to form 2 or 3 triangles on the ground before high-altitude installation which could be consequently reduced.

2. Apply adjustable small gin pole hangers to realize lifting and installation of the small-piece units

3. Set safety piles around the doom area to compensate the wind influences with lassoes, the amount and position of safety lassoes should be altered with the increasing installation height of the building, and safety lassoes should be added on the windward side when the erecting height reaches 3/4 of the planning height.

4. Weld “L” steel in the purlin pallets of the grid, and complete the welding and drilling procedure of the “L” steel on the ground to realize direct binding of the purlin pallets and the

bolts at high-altitude for accelerating the erection.

5. Use large-sized plates with the length of 8m~12m to install, and apply both manual pulling plates and adjustable small gin pole hangers to lift and install the plates to the installation working face.

2. A super-long span double-layer space grid dome erecting technique according to claim 1, characterized in that the small-piece unit mentioned above is composed of two bolt balls and eight pieces of members

3. A super-long span double-layer space grid dome erecting technique according to claim 1, characterized in that the height of bearing and the roundness of the closed circle should be controlled when the first circle in the circle-by-circle closing method is installed. The height of bearing should be adjusted by steel sheets with different thicknesses, and the roundness should be adjusted by the cross beam and the jack. The bearing should be welded and immobilized for the first time after repeated adjustment making sure the installation error is within the limits permitted by the specifications. Every circle should be checked when closed to guarantee the overall rigidity of the doom and keep errors from accumulating. Also the roundness and closing error of the overall installation project should be checked and adjusted when the installation of the second and third circles of the grids are completed to make sure all the indexes meet requirements of the specifications before the final welding and installation of the bearing. Afterward, the installation and closing should be carried out circle by circle, and the structural roundness should be checked and adjusted each time three circles get done using tension from steel cables of anchor blocks.