

## Research on the Retrofit of Spatial Roof Based on Fixed Support and Connection Technology of a Metal Roof System

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### Abstract

To solve the problem of insufficient bearing capacity or unable to normal use of space roof caused by function change, structural damage, and termination of service, the test evaluation, concept design, numerical simulation, and the application of engineering methods were used to innovatively put forward the demolition reconstruction scheme of changing the “shed roof structure” to “double slope roof structure”, develop the steel truss demolition method of “fragment dismantling at high altitude and manual dismantling on the ground”. Meanwhile, a fixed support and connection technology of metal roofing system was invented to solve a series of problems, such as large original roof structure windward area, weak ability to resist the typhoon bad weather, and poor ability of the original metal roofing to resist wind pressure, and easy to crack, and then the safe, economic and efficient demolition and reconstruction of the existing space roof structure under the premise of keeping the original body structure in good condition, providing good technical support for the reconstruction of existing space roofs in China, and helping the upgrading of existing urban-industrial areas and urban renewal.

**Keywords:** Metal roof, Connection technology, Fixed support, Space Roof

### I. Introduction

Over the past 40 years since the reform and opening up, China's construction industry has made remarkable achievements, with more and more mature construction technologies and a large number of “century” projects<sup>[1]</sup>. However, as a large number of projects are unable to continue their service due to the expiration of the service period or the influence of external factors, the normal function of the buildings is damaged or the bearing capacity is difficult to meet the standard requirements, especially in the severe typhoon area, the large-span space roof structure is easy to be damaged. If the existing damaged buildings are demolished and rebuilt, it will cause a lot of manpower and material resources waste, and the cost will be very high. In recent years, scholars around the world have carried out a series of researches on the reconstruction of existing roof structures, focusing on the reconstruction design of the roof, the way of roof removal as well as the design of the metal roof, which are not systematic, especially the large-span space roof structure.

### II. Research on Reconstruction Design of Space Roof

In view of the problem that traditional roof reconstruction design mainly focuses on residential buildings<sup>[2]</sup> and the research on the existing spatial roof structures is not systematic, in this paper, a systematic research was carried out on the reconstruction design of the existing spatial roof structures, and the following research results were obtained

from the perspective of preliminary planning and architectural design:

(1) Preliminary planning

On the basis of investigating, classifying and analyzing the roof forms that need to be reconstructed, a whole feasible transformation technique should be studied, and the technique should be extended to the roof landscape beautification and meet the demand of both the new function space, so as to merge with local construction of humanistic environment better and achieve the goal of reconstruction.

(2) Architectural design

1) "The plane is changed to single-slope or multi-slope roof". After the reconstruction, the scale of slope roof is high and the internal space is large. On the one hand, it can improve the structural mechanical performance of the roof under the action of extreme external forces such as typhoon load, and on the other hand, it can accommodate more equipment and other functional requirements.

2) After the reconstruction, the slope roof forms are complex and have strong characteristics, which can not only meet the transformation strategy of different architectural styles, such as antique, European, modern, etc., but also provide different cost forms according to different needs, and then adjust measures to local conditions according to the principle of economy, safety, use, and reliability, thus achieving the best effect.

3) New technology is applied to the sloping roof after reconstruction to adapt the building to the development of the new era. Combined with passive energy-saving technology, such as the installation of photovoltaic energy-saving panels, roof rainwater reuse and other new technologies, the building is given characteristics of the new era.

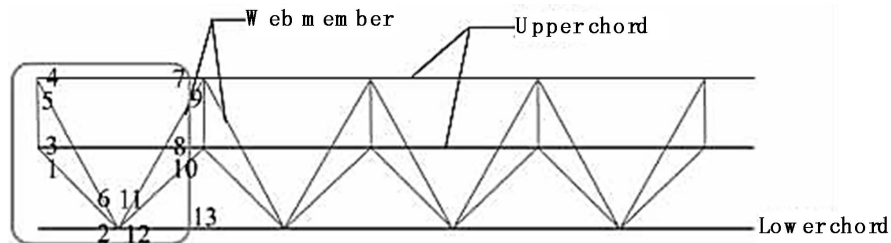
4) After the reconstruction, the slope roof realizes the assembly concept and forms expanded production. And the most efficient and economical roof structure is vigorously promoted from the whole industry chain of design, manufacturing and installation.

### III. Research on Roof Removal Technology

To solve the problems such as large span of steel grid roof structure, no damage to the original main structure in the process of demolition, and the need to put in a lot of support measures and uneconomic lifting machinery for the overall demolition, the demolition method of "fragmented demolition at high altitude and manual disintegration on the ground" was proposed. Firstly, by analyzing the mechanical characteristics of the structure and carrying out demolition construction simulation, the division of demolition units of the steel grid roof structure was determined. Secondly, taking into account the stability of the remaining parts of the truss after the fragment disassembly during the demolition process, temporary support measures should be set up at the dismantled joints during construction. Thirdly, large equipment located on the outside of the building was used to lift and dismantle the steel grid roof structure. Finally, artificial disintegration was carried out on the ground.

When each truss was dismantled, in order to prevent the dismantled truss from imposing sudden load on the scaffold and truck crane, that is, the load of the dismantled truss can be converted from the original structure connection to the crane and supporting scaffolding step by step, the method of "40% ~ 60% structural self-weight load should be added by the truck crane before cutting all the grids + the chain should be tightened before cutting the upper and lower chords of the grids (bound by the obvious force generated by human pulling)" was proposed, aiming to ensure that the upward-lifting force of all the grids was basically equal to the self-gravity. The cutting direction should be the way of supporting and then removing, first removing and then main removing, first tensing and then cutting. The overall order was to achieve the goal of self-bearing of the grid frame.

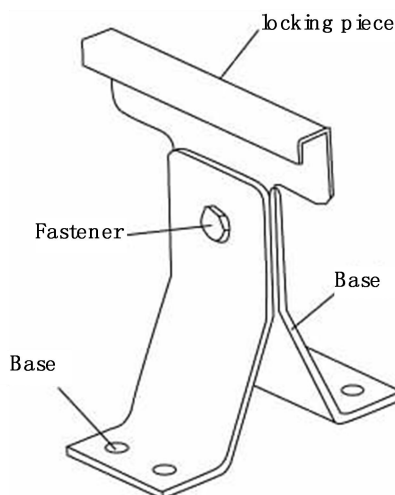
After the grid frame was removed to the ground, it was cut and disassembled on the ground with flame from one end to the other, as shown in Figure 1. First of all, the end belly rod and 2/5/1/6/3/4 of the bolt ball node overhanging circular tube were cut. Secondly, 7/8 of the upper chord rod was cut. Finally, another set of belly rods and bolt-ball nodes 9/10/11/12 were cut, and the cycle was repeated until the disassembly was completed. Attention should be paid to prevent local deformation during on-site cutting. After cutting, the single bar should be neatly laid out according to the requirements, and uniformly transported to the field for treatment after decomposition.



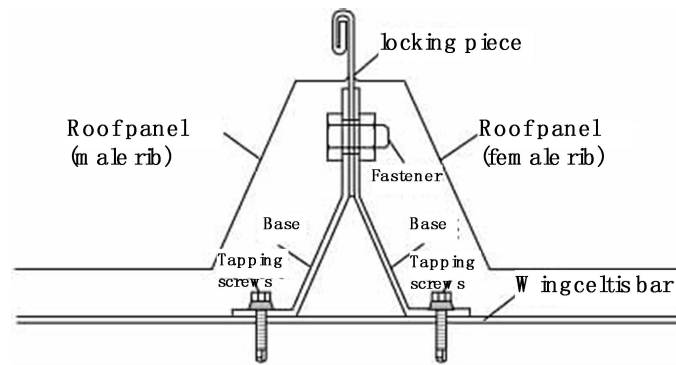
*Fig 1: Ground disintegration diagram*

#### IV. Research on Metal Roof Design

The traditional connection mode of fixed support and roof plate has some shortcomings in use or reconstruction. In this paper, a new connection mode of metal roof fixed support and roof plate was invented. The new fixed support (Fig. 2) consists of a galvanized steel base and a stainless steel locking piece. The galvanized steel base is symmetrically separated and can be fixed to a purlin with self-tapping nails. The locking piece and the base are connected by stainless steel bolts, which can rotate relative to each other and the locking piece is connected with the roof plate in a locking manner (Fig. 3). When using the metal roofing board fixed support to fix the metal roof panels, there is a gap between the metal roofing plate and the base, and the two do not contact, which avoids the metal roofing plate from producing friction with the base when there is deformation, so as to prevent damage of the coating of the metal roof board. Besides, the fixed support has a simple structure, hasn't too many complicated shapes, and is easy to manufacture, so it can reduce the cost to some extent.



*Fig 2: Axonometric drawing of fixed support*



*Fig 3: Occlusion molding of fixed support and roof panel*

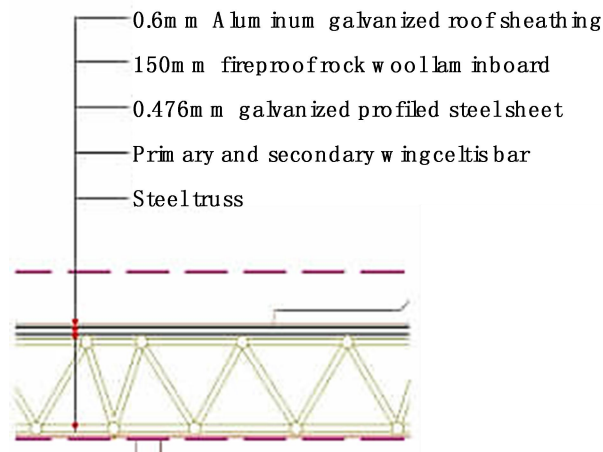
The connection mode between the new fixed support and the roof plate of the metal roof has the following advantages: (1) the fixed support has a simple structure and high processing efficiency, and can save the production cost; (2) The fixed support is relatively complex and special-shaped, with high utilization rate of transportation, and can save the transportation costs; (3) The fixed support is not in contact with the roof plate to avoid the relative sliding friction between the roof plate and the fixed support when the roof plate is deformed, avoiding damages the roof plate coating and leakage points; (4) The field installation of the connecting fasteners of the fixed support is convenient, and it is not limited by the space of the fixed support structure, thus improving the installation efficiency and quality.

## V. Application of Space Roof Reconstruction Project

### (1) Project Overview

Dapeng New Area, as one of the “eight most beautiful coasts in China”, is surrounded by sea on three sides. In the most southern part of the subtropical climate, it is rainy and foggy all the year round, and it is often attacked by typhoons. Meanwhile, the sea breeze tuyere is located in the southeast, and the wind speed is large.

Dapeng Cultural and Sports Center is located at the intersection of Renmin Road and Pengfei Road, Dapeng Street, Longgang District, Shenzhen. It is a sports building and supporting office project with a total construction area of 8063.01 m<sup>2</sup>, and its original main structure is concrete frame structure, and the roof is made of curved curved color steel plate. The roof structure is divided into two parts: north and south. The maximum span of 4 trusses of steel grid frames from east to west is 43 m, and the maximum span of 6 trusses of steel grid frames from north to south is 42 m. The maximum cantilever of the south side is about 29 m, the minimum cantilever of the north side is 16m, and the height of the upper and lower layers is 2.0 m. The thickness of the roof panel (Fig. 4) is 150mm, in which the metal roof is 0.6mm aluminum galvanized roof boarding.



*Fig 4: Schematic diagram of the original roof structure*

Affected by Super Typhoon Mangkhut in 2018, part of the roof of Dapeng Cultural And Sports Center was seriously damaged. A large number of aluminum plastic panels fell off on the windward side of the roof, and the lighting film in the middle of the roof was also in urgent need of repair and replacement due to aging. The architectural function of the entire cultural and sports center has been seriously affected, so the renovation of the roof is urgently needed.

#### 1) Reconstruction design concept

In the reconstruction design of the existing space roof structure, it is necessary to ensure its safety and reliability, so as to avoid the recurrence of roof damage. In the reconstruction design, it is necessary to take into account the following aspects: ① The reconstruction part of the roof must have the ability to withstand severe and extreme weather; ② Reflect clean, beautiful, intelligent and modern characteristics; ③ Reflect the characteristics of harmony with the surrounding environment; ④ Reflect the characteristics of science, energy-saving and environmental protection; ⑤ Consider the economy and efficiency of roof renovation to improve the cost performance.

#### 2) Reconstruction design scheme

Because Dapeng Cultural and Sports Center is located in the seaside, it suffers from all kinds of storms and typhoons all the year round, and the original roof structure is single-slope structure with a large windward area, which leads to high wind pressure on the roof structure under the action of severe typhoons and is easy to cause the metal roof plate to tear. The cantilever part of the roof structure also greatly enhances the effect of the wind force brought by the severe typhoon, which causes strong damage to the metal roof panels. Therefore, through the comparison and analysis of multiple schemes, finally, it was determined to reconstruct from "shed roof structure" to "double slope roof structure", and the roofing system adopted the demolition reconstruction scheme of aluminum plating zinc metal roofing system. The scheme has the following advantages: ① the design of windward slope roof can effectively reduce the windward side area of the building, and enhance the ability of building to resist severe typhoon weather; ② The same aluminum-plated zinc metal roof system as the one in Shenzhen International Exhibition was adopted, which has been verified by typhoon "Mangokhut" and shown excellent wind resistance performance; ③ The design method of combining "truss structure" with "double slope roof" and reconstructing the existing outer columns was adopted to merge "modern" and "traditional" merge, thus reflecting the characteristics of Shenzhen's "dynamic city" as well as the "classical beauty" of Dapeng Ancient City; ④ The activity area and supporting functions of the stadium were cleverly designed as double pitched roof, so that the facade of the

building forms the gable form of Chinese traditional residential buildings, which echoes Dapeng Ancient City not far away; ⑤ As it is a reconstruction project, this design will change the existing building structure as little as possible, maintain the integration of the existing architectural style and some elements of the renovation, and at the same time, it is convenient for rapid construction, and has good economic benefits.

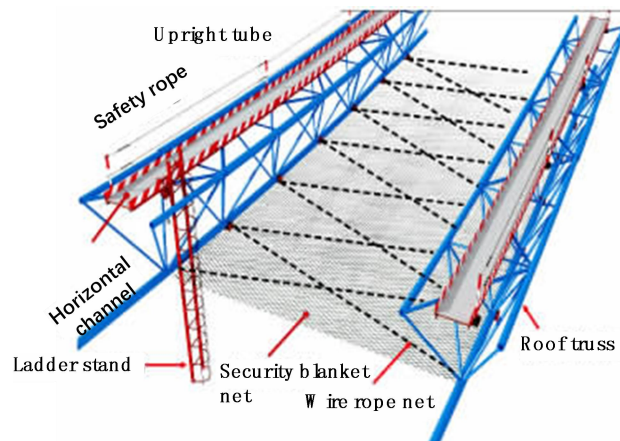
## (2) Safety control technology of demolition

1) The demolition unit division principles include: ① The weight of the fragment network frame shall not exceed 80% of the performance of the crane; ② The cutting point should be avoided to set at the network frame nodes as far as possible; ③ The direction of the fragment should be parallel to the direction of the grid as far as possible; ④ The size of the fragments should not be too large to facilitate lifting; ⑤ The location of the fragment should be conducive to construction operation.

## 2) Research on demolition safety control technology

When removing each truss from high altitude, the two ends of the truss shall be cut simultaneously according to the sequence of fragments. During the cutting, the operator shall hang the safety belt on the wire rope pulled on the remaining fixed truss part, and then use the springboard laid on the lower chord of the grid frame to carry out a flexible station position. In order to prevent the swing caused by stress concentration between the cut pieces and the remaining pieces when the last tube is cut, making the operator slip and fall, so in combination with the stress characteristics of the truss structure and the position of the cutter, the cutting sequence is set as follows: the upper chord, the lower chord, and the web member. The upper and lower chord tubes have a larger diameter and a thicker wall thickness. After removal, the web member can be deformed to release some stress, which is conducive to the demolition stability.

Demolition of steel grid roof is a risky construction activity. Combined with safety and operability, this paper innovatively proposed a set of safe operation platform and personal safety protection measures applicable to the demolition of steel grid frame (Figures 5,6).



*Fig 5: Security measures*

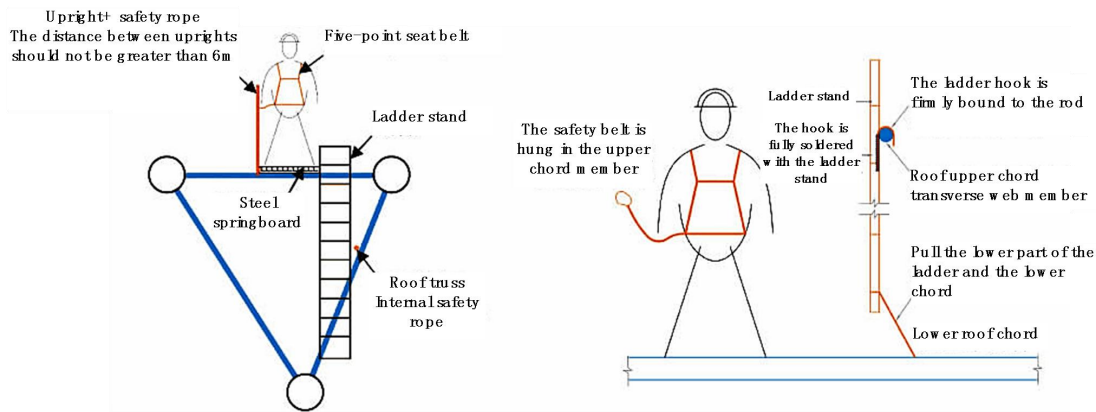


Fig 6: Personal safety protection measures (in the upper and lower chord positions respectively)

### (3) Construction method of metal roof

The assembly method of the new connection mode is as follows:

- 1) First of all, assemble the parts contained in the fixed support, connect the base and the locking piece together with fasteners, and then tighten the fasteners.
- 2) Before installing the fixed support, the theodolite is used to measure the roof line, and then the fixed support assembled with self-tapping nails is used to fix on the roof purlin.
- 3) After the installation and check of the fixed support, the roof plate male ribs are installed first. When they are installed, as the weight plate width direction has a certain degree of bending, it can be used to reduce the width of the flexural, and at the same time, the roof plate male ribs can be artificially moved, and the locking part of the roof plate male ribs can be installed into the locking piece of the fixed support in an inclined way.
- 4) After installing the male ribs of the roof plate, install the female ribs of the roof plate, and the male ribs of the roof plate can be directly placed on the top of the locking piece. After the female ribs of the roof plate are installed, the metal roof locking machine (electric) is used for 360° occlusion of the locking plate, the male ribs and female ribs of the roof plate. After the occlusion is completed, the locking piece is closely connected with the roof plate, with good wind resistance and waterproof performance. Meanwhile, the locking piece and the roof plate do not slide, and can rotate synchronously.

The problem of unreasonable stress of the original roof structure in the severe typhoon area was solved by proposing the scheme of demolishing and rebuilding from “single slope roof structure” to “double slope roof structure”. The proposed construction method of “fragment demolition at high altitude and artificial disintegration on the ground” for the demolition of the steel grid structure is very beneficial to the construction of new projects where the site is relatively open, the lifting equipment cannot be installed in the site, and the problem of demolishing the existing spatial roof structure under the premise of retaining the main structure is solved. Meanwhile, a fixed support and connection technology of the metal roof system was invented to solve the problem that the traditional metal roof is easy to tear. This technology provides a complete solution to the reconstruction of similar existing space roof structures, which not only provides good technical support for the reconstruction of existing space roof in China, but also helps the upgrading of existing urban industrial areas and urban renewal.

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