Safety Analysis of Wood Frame Shoring Structure Under Static State

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Abstract. The wooden structure shoring technology is earthquake site on the damaged building temporary reinforcement of the most effective measures, more efficient and accurate operation can not only support the wood structure for the precious time for the trapped in the field, can provide security for a field work environment. Wood frame shoring technology is the temporary reinforcement measures of the damaged building structures and the key subjects for the training of the rescue team. More efficient and accurate construction of wood support operations can not only for the trapped people to fight for valuable time, but also for the on-site work environment to provide considerable security. In this paper, the finite element analysis results reflect the stress characteristics, weak links and suggested improvement measures of the whole supporting structure, which provide the theoretical basis for the safety rationality of wood structure shoring.

Introduction

As the earthquake caused the collapse of a large number of houses, many trapped people were buried under various structural forms, such as brick and concrete structure, frame structure, masonry structure and so on. In the disaster scene, how to use all kinds of rescue tools to ensure timely and effective rescue under the premise of ensuring the personal safety of the buried personnel and rescuers is an important topic for earthquake rescue work. In order to ensure the safety of their own and trapped people after rescuing the trapped persons after the earthquake, rescuers should support and stabilize the collapsed building structures in a timely and effective way. The construction of earthquake rescue passageway is of great significance for improving the efficiency of earthquake rescue and reducing casualties in the earthquake. And the key to open up rescue channels is effective support structure. The support technology in the post earthquake rescue is the key to ensure the safety of the rescuers, and is also an important aspect of the rescue after the earthquake.

At the end of twentieth Century, according to the situation of the post earthquake and the experience of many post earthquake rescue, European and American developed an advanced professional rescue equipment, and played a very important role in the rescue process after the earthquake. However, professional earthquake rescue shoring equipment is very expensive, facing the ruins rescue, shoring often can not be recycled, causing great waste. The wooden structure shoring technology is earthquake site on the damaged building temporary reinforcement of the most effective measures, more efficient and accurate operation can not only support the wood structure for the precious time for the trapped in the field, can provide security for a field work environment. Since the rescue work after the earthquake is very complicated, up to now, the rescue principles and search technologies of the trapped people in the world are often emphasized only in the post earthquake rescue work. However, there are no specific technical regulations and standards about the rescue support structure after the earthquake. Although some typical supporting structures have been used as training bases in the national earthquake emergency training base, they have not really invested in the post earthquake emergency rescue. By summarizing the past experience of earthquake rescue, people realized the effectiveness of some supporting methods or supporting structures. However, model tests were not systematically adopted to find the size of members that could maximize their bearing capacity. Therefore, this study will address the status of the earthquake relief support structure of the
lack of systematic study in China, combined with the damage characteristics of different building structure, adopts finite element analysis method, to analyze the typical supporting structure stress characteristics, weak links, and puts forward some improvement measures, provide a theoretical basis for the safety and rationality of wood structural support.

Methodology

Definition of material properties and sections

The tools used in this modeling are Midas civil for general purpose space finite element analysis software. Before modeling, it is necessary to define the material properties and the section of the structure support model. According to the recommended types of wood in U.S Army Corps of Engineers Urban Search and Rescue program: shoring Operations, this modeling uses FIR as a material. According to the mechanical parameters of the standard Chinese fir, the modulus of elasticity is set to the unit weight. The material type is isotropic because it only considers the stress state of the supporting structure under static state. Due to natural growth, the mechanical properties of wood are anisotropic. In the actual support operations, the use of wood is the size of the same square long wood, the general size of the square wood and the wood, the material is a homogeneous regular graphics, so do not take into account the eccentric effect, set the same size section as shown in figure 2.
Definition of Boundary conditions

In the finite element modeling, we need to specify the boundary condition and the connection condition of the model. The simulation of FEM results can be improved by simulating the constraint condition of the connection position. The connection is generally divided into the following three kinds.

**Boundary conditions between the components**

Connections between the components, such as roof and upright posts, generally depend on a two-way fixed node plate. The contact position of the node plate and the wood will be connected by using a triangle or extending the triangular nail nails. Therefore, the end of the component is bound by the friction force of the nails and the interaction force of the nodal plate along the axis Z axis, so the displacement cannot be produced, and the shearing force of the nails cannot be produced in the direction of x and Y axes. So the connection points are set to rigid constraints during the simulation.

**Boundary conditions for timber structure shoring and contact surfaces**

The boundary conditions of the wood support structure and the contact surface are generally squeezed by each other. For example, for a single t support, the roof and top of the supported objects squeeze each other, the bottom floor and the ground under each other. Since the extrusion pressure is always perpendicular to the contact surface, the boundary conditions of the contact surface are generally set to be perpendicular to the contact direction (usually the X or y axes), and the remaining two directions are not bound.

**Boundary conditions of wood wedge and shoring member**

The wood wedge in the actual operation will first hit the important, and then the two sides of the nails into the steel nails, so the wood wedge and the supporting members of the boundary conditions for the X and y-axis constraints, the z-axis is not bound.

**Simulation and demand analysis of wood wedge**

Wood wedges appear in almost all wood-frame supports, its function mainly is: (1) can play the regulation function in the length, (2) can apply prestress (all pressure) to the structure, make the support structure and the supported object full contact, conduction load, limit the displacement of the supported object, reduce the risk of two times collapse. Therefore, it is necessary to study the mechanical characteristics of the wood wedge itself. In the finite element modeling, the wood wedge is modeled separately and the load is applied at the contact position in order to observe the force characteristics of the whole wood wedge. In the actual modeling, the model can be simplified to omit the wood wedge, because in practice, it is necessary to have the important support structure to have the contact surface and the force conduction, while in the modeling can add the load directly, Has little effect on the simulation results.

Fig.4. Establishment of wood wedge joint and its boundary conditions

The wood wedge itself is a pair of two triangles, after the impact on the two-wooden wedge at both ends can be relied on friction, to achieve the fixed structure of the entire wood supporting the role, so in the compression action is as the entire rectangular unit under pressure, and the contact surface of the component is more pressure.
Fig. 5. Finite element analysis diagram of wood wedge

**Modeling Process of Wood Structure Shoring**

In this paper, several kinds of wood structure support, such as Single T Shoring, double pillar support, oblique support, flying type support structure, are modeled and analyzed.

**Single T Shoring modeling process**

Single T Shoring is a temporary support before the full support system is erected. First, the whole damaged area is investigated in detail, the risk factors such as load eccentric displacement or structural instability are determined, and the whole supporting operation area is cleaned, the uneven ground and the soft foundation are measured, and the total height of the supporting position is reduced, and the preset height of the top, bottom, wedge and the height of Then in the safe area of prefabricated T-point pillars and top (glued joint joints need double-sided reinforcement), the single T support in the load center position, pay attention to the sliding column and wedge chassis in place and check the support system is vertical, strengthen the wedge to the compaction state. Finally, the lower half of the joint Board is installed to cover the ceiling and floor. The single T support is constructed with pneumatic support, hydraulic support, Ellis clamp and screw jack. Based on the unknown stability, the design load takes 1000-4000 lbs.

Fig. 6. Diagram of single T support and node unit

First, according to the roof and the bottom plate 1m, the length of the column 3.4m to establish a node, because the single T-supporting timber only a single size, so in the node position to add 1 section to form a continuous unit. Add a connection at the structure junction and set the boundary conditions at the contact position. In order to simulate the stress situation of single t support under
static conditions, the load is loaded vertically and the load is 4.3kn/m in the roof position. The model is analyzed by finite element method, and the analysis results are derived.

Double Column Shoring modeling process

The double columns vertical Shoring is a Shoring form for short-term internal energy, which is superior to single T Shoring and double T Shoring. When operating on the ceiling and the floor, fixed the vertical shoring of the roof and the bottom plate, fixed in the roof of the column spacing of not more than 1.5m, the allowable tilt value.

First, the three height values (two edges and middle positions) of the shoring surface are measured, and the minimum value is taken as the ultimate support height. Note that the roof, floor and column should use the same size of wood, at the time of calculation, the top, bottom, and the preset height of the wedge (usually the cross-sectional dimensions of the wood) shall be reduced, and the calculated cutting list shall be submitted to the feeder, and the supporting member should be made as much as possible in the safe area.

Place the upright column on the flat ground and align the roof, double-sided fixed diagonal of the node plate and the middle part of the supporting member, then move the support structure to the middle position of the load, the bottom plate moved to the correct position, and the wedge placed under the Upright column, check the support structure is perpendicular to the ground, check stability, and then strengthen the wedge, install the bottom node plate and make double-sided fixing. If possible, make sure that the roof and floor of the supporting structure are close to the superstructure and floor.

First, according to the roof and bottom 2.3m, column 3.5m, column spacing 1.7m, oblique strip distance of the edge 0.1m length size of the node, two pillars supporting the roof, floor and pillar used
timber, in its two pillars of the use of wood strips to form a similar steel structure truss structure, effectively increased the entire structure of the bearing capacity. The strips fixed in the middle part of the column are consolidated at both ends and columns, two oblique strips from the middle part of the column began to penetrate to the top floor, respectively in the middle of the column, the lower end and the top floor of the edge of the consolidation, pillar and roof combination of the position also do curing, the top floor and the supported surface and the foundation of the boundary conditions limit the x-axis in order to simulate the force of the double pillar support under static condition, the load in the roof position is loaded, the loading direction is vertical downward and the load is 4.3kn/m. The model is analyzed by finite element method, and the analysis results are derived.

**Recline Shoring modeling process**

The oblique support is mainly to support and protect the vertical structure system of the wall with collapse risk and the corridor with cracks. General oblique rod tilt angle for 45°, the splint nailed to the wall board, the minimum size of the splint 60cm, using 14-16d nail for fixed. If the tilt angle is 60°, the 80cm splint is used.

Assemble the retaining wall plate and the oblique bar, and pin the node plate in the connecting position. The vertical wall is placed on the bottom plate and is connected using a node board and a wall panel (note: It can be temporarily fixed with a hoof nail). From the connecting position of the wall board and the bottom plate to the middle position of the oblique rod, fixing the wood strip and fixing the single node plate on the oblique rod, the bare part at least 5cm from the bottom of the oblique rod. The reverse support structure is fixed in the same way in the opposite direction. Finally, the whole support structure is erected, the bottom splint is fixed properly, and the position of 4cm wedge is reserved.

First, according to the protection wall plate and the bottom 2.0m, oblique rod tilt angle 45°, oblique bar edge from the protection wall plate and the edge of the floor are 0.4m, oblique strip connecting the middle part of the oblique rod and the wall plate of the structure set up a node. The Timber section of the oblique supporting wall plate, the bottom plate and the oblique rod, the Timber section added by the oblique strip. The position of the oblique bar is consolidated with the retaining wall and the bottom plate, the two ends of the oblique strip are consolidated, the contact position of the bottom plate and the ground is restrained in the direction of the X axis, the right end of the bottom plate is constrained by the anchor point or natural rigid body for the actual operation, so it is set to the consolidation state when the model is modeled. To simulate the force of the oblique support under static conditions, the load is loaded at the position of the supported wall, the loading direction is horizontally to the right and the load is 4.3kn/m.

**The flight type Shoring modeling process**

The flight type Shoring is used as a temporary support in the field and can be considered for use in the following steps only if other permanent support can be placed.

Select a safe area to expand the operation, determine the fly-shaped support on the supported wall of the insertion point height, from the ground edge 0.6m. The wood is cut to make the bevel column according to the design length, and the cutting way and the oblique support are the same. Nail the splint to the wall panel and install the bevel and gusset plates. Mount the bottom brace at the position where the bevel column extends to the ground. Then move the bevel column to the correct position and anchor at the bottom. Connect the wall, tighten the wood wedge, fix the bottom, pass through the bevel, and hold the flying support.

First, according to the wall board 1.0m, oblique rod m, tilt angle 45°, middle wood strips 1m, middle strip connecting oblique rod and the middle part of the wall plate to establish the structure of the node. The Timber section of the oblique supporting wall plate and the oblique rod is added, and the middle strip adds the Timber section. The connecting position between the inclined rod and the retaining wall plate and the middle strip is consolidated, the two ends of the middle strip are consolidated, the contact position between the oblique rod and the ground is due to the wooden groove on both sides, the end has the anchor point, so the displacement is restrained along the x-axis and the z axis. To simulate the force of the oblique support under static conditions, the load is loaded
at the position of the supported wall, the loading direction is horizontally to the right and the load is 2.0kn/m.

![Figure 9. Schematic diagram of flight Shoring and the establishment of node unit](image)

**Results**

**Single T Shoring finite element Method Analysis Results**

**Axial Force (\( F_N \)) analysis results**

According to the analysis result, the single T support structure will produce the axial force in the pillar part, the axial force size is negative, the overall pressure, because the column section all is the square section, therefore the axial force size has not changed. For the stability of the rod can be brought into the Euler formula \( F_{cr} = \frac{\pi^2 EI}{(\mu l)^2} \), for both ends of a fixed slender rod \( \mu = 0.5 \), and then the selected wood bending strength (EI), can be calculated to cause the column instability of the load size of the approximate value.

**Shearing (\( F_S \)) analysis Results**

According to the analysis result, the single T support structure will be subjected to shearing force at the top roof position, the left side of the column is counterclockwise shear (negative shear force), the right roof of the column is clockwise shear (positive shearing force), the shear force is the length of the force and the load size of the product, and at the root position for the maximum shear. This is because the roof ends for the cantilever end, under the uniform load, shear will be from the end to the root of the linear uniform increase state, so if the larger load, the root has cut risk. No shear exists in the rest of the components.

**Bending Moment Analysis Results**

According to the analysis results, the single T support structure in the top roof position due to the effect of the above uniformly distributed load, will be along the cantilever end to pillar support to produce negative moment, two times parabola distribution, and at the root position to reach the maximum bending moment \( M_{MAX} = \frac{1}{2} ql^2, q = 3.4kN/m, l = 0.5m \). Left bending moment and right end moment are equal in size. The remaining members do not produce bending moment.
**Double Column Shoring finite element Method Analysis Results**

**Axial Force ($F_N$) analysis results**

According to the analysis result, the double pillar support structure will produce the axial force in the pillar part, the upper oblique strip and the middle stripe belt, the two pillars are the compressive stress, the upper oblique strip and the middle strip are the tensile stress. The connecting position between the inclined strip and the right column to the right column and the top floor is the largest place of the compressive stress value, and the middle strip is the maximum tensile stress.

**Shearing ($F_S$) analysis Results**

According to the analysis result, the double pillar support structure will be subjected to shearing force in the top roof position and the upper part of the column. The left cantilever end of the roof is subjected to negative shearing force, the right cantilever end is subjected to positive shears, and the left half of the top of the two columns is subjected to positive shear, and the right half is affected by the negative shear force, the root shear force at the position of the column and the roof is the maximum. Therefore, in the case of large load, the root position of wood or node plate has the risk of shear damage.

**Bending Moment (M) Analysis Results**

According to the analysis result, the roof position of the double pillar supporting structure is affected by the above uniform load, the negative bending moment is produced along the cantilever end to the support of the pillar, which is two times parabolic distribution, is pulled under the roof of the two columns, the upper surface is pressed, and the maximum bending moment is in the middle of the roof, which is a positive bending moment. The upper half of the two columns also have bending moment, but the bending moment is smaller than that of the roof. Therefore, in the case of large upper load, the roof has the risk of bending, it is possible to appear under the wood splitting, transverse cracks phenomenon.
Recline Shoring finite element Method Analysis Results

Axial Force ($F_N$) analysis results

According to the analysis result, the oblique support structure will produce axial force on the retaining wall plate and the oblique rod, the connection between the retaining wall plate and the oblique rod is tensile stress, and the oblique bar behaves as compressive stress, mainly because of the uniform load of the wall, which forces the connecting point of the wall and the oblique rod to move horizontally to the right, when the retaining wall plate is stretched and the oblique bar is compressed. It is noteworthy that the diagonal strips do not produce axial force, this is mainly because the role of the oblique strip is to prevent the oblique rod in the excessive pressure to produce instability, so the axial force of the oblique strip in the oblique rod random instability, may be shown as tensile stress, also can be expressed as compressive stress. In this model, the oblique bar does not exceed the limit of its flexural strength, so there is no bending, so the oblique strip does not produce axial force.

Shearing ($F_S$) analysis Results

According to the analysis result, the oblique support structure will be subjected to shearing force in the position of the retaining wall plate, and the connecting place of the retaining wall plate and the oblique rod is the cantilever end position. The negative shear force is generated by the uniform load of the wall, and the upper edge to the node is linearly increased, and the upper part of the retaining wall plate and the oblique bar connecting to the lower edge position is the positive shear force. The lower part is negative shear force. The analysis results show that the maximum shear position is in the connection between the retaining wall plate and the oblique rod, therefore, in the case of large load, the timber or node plate at the junction has the risk of shearing damage, and the connection between the wall panel and the backplane is also a high-risk point.

Bending Moment (M) Analysis Results

According to the analysis result, the position of the oblique supporting structure at the cantilever end of the retaining wall plate is affected by the horizontal and right uniformly loaded load. Will be along the cantilever end to connect everywhere generated negative moments, a parabolic distribution of two times, at the junction to the lower edge of the retaining wall plate under the surface under the tension, the upper surface under pressure, in the middle position of the wall plate for the maximum bending moment, for positive bending moment. Therefore, in the case of large lateral loads, the risk of bending the retaining wall plate, there may be wood lateral splitting, longitudinal cracks phenomenon.

The flight type Shoring finite element Method Analysis Results

Axial Force ($F_N$) analysis results

According to the analysis results, the fly-shaped support structure will produce axial force on the retaining wall plate part (not cantilever segment), the bevel section and the bottom strip. The connection between the retaining wall plate and the oblique rod is tensile stress, and the oblique bar behaves as compressive stress, mainly because of the uniform load of the wall, which forces the connecting point of the wall and the oblique rod to move horizontally to the right, when the retaining wall plate is stretched, the diagonal bar is compressed. The tensile stress exists in the middle strip, which is mainly because the middle strip can help to limit the horizontal displacement and rotation of the oblique rod, and can also effectively reduce the bending moment of the oblique rod, and can help to improve the stability and strength of the supporting structure. The maximum compressive stress is
located in the lower part of the oblique rod, so if the load is too large, it may cause the compression deformation or instability of the lower half of the oblique rod.

**Shearing** \( (F_s) \) **analysis Results**

According to the analysis result, the flying support structure will be subjected to shearing force in the position of the retaining wall plate, and the connecting place of the retaining wall plate and the oblique rod is the cantilever end position. The negative shear force is generated by the uniform load of the wall, and the upper edge to the node is linearly increased, and the upper part of the retaining wall plate and the oblique bar connecting to the lower edge position is the positive shear force. The lower part is negative shear force, the middle strip is affected by negative shear force, and the whole of the oblique bar is negative shear. The analysis results show that the lower part of the oblique bar is the maximum shear position, so the lower part of the oblique bar has the risk of shearing failure, and the fracture and deformation may occur in the case of large load.

**Bending Moment** \( (M) \) **Analysis Results**

According to the analysis results, in the lower half position of the oblique bar, the fly-shaped bracing structure produces positive bending moment at the position of the anchor point along the connection to the lower part of the slope, which is two times parabolic distribution and the maximum bending moment at the anchor point position. Because the upper part of the oblique bar, wall panels and the middle strip will form a more stable triangle, therefore, the lower half of the oblique bar is the maximum bending moment value, in the case of large lateral load, the lower part of the inclined rod has the risk of bending, it is possible to produce a certain degree of deflection downward, the anchor position may appear dislocation, rotation, the wood may be split, Deformation of the phenomenon, can be considered in this position to increase the shield or cushion to improve the mechanical properties of this component.

![Fig.13. Axial force, shear force and bending moment diagram of fly-type Shoring](image)

**Conclusions**

This study will address the status of the earthquake relief shoring structure of the lack of systematic study in China, combined with the damage characteristics of different building structure, adopts finite element analysis method, to analyze the typical supporting structure stress characteristics, weak links, and puts forward some improvement measures, provide a theoretical basis for the safety and rationality of wood structural support.

There are some deficiencies in this study. First of all, it is not possible to simulate and analyze the stability of the braced structures under the influence of aftershocks by adding the reaction spectrum equation into the finite element modeling and only simulating the supporting structure under the static load state. Secondly, the structure of the support of the form is not refined, only selected a more typical types of support, in the structure of the type of support is slightly missing.

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