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Preliminary communication

Experimental Study on Bearing Capacity of Glass Bridge Deck under Different Wheel Compression Positions

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Abstract: In order to solve the problem of lighting in the building structure, landscape area or car city and the vehicle yard to achieve green energy saving, it is proposed to replace the full concrete bridge deck scheme with the glass bridge deck and concrete bridge deck, and to utilize the light transmittance of the glass material. In order to explore the technical feasibility of applying glass bridge panels to automobile passages, the paper intends to carry out the bearing capacity test of three-layer PVB glass sheets and single-layer glass bridge decks under different wheel pressures under the wheel load, paying attention to the continuity of load application and researching the load, respectively the force of the glass plate when acting in different positions. Six laminated glass plates and three single-layer glass plates were designed and fabricated, and the rubber load was used to simulate the wheel load for test loading. The ratio of the bearing edge and the plate angle of the single-layer glass to the load at the center of the plate was 78.7% and 64.8%, respectively. The ratio of the bearing edge of the laminated glass and the plate angle of the laminated glass to the load was 98.3% and 86.5%, respectively. For laminated glass, the effect of the load position on the ultimate bearing capacity of the glass sheet is weaker than that of the single layer glass. The ultimate bearing capacity under wheel load acting on the center, side and corner of the laminated glass plate is 2.78, 3.47 and 3.66 times of that of the laminated glass plate at the same position. The test results in this paper can be of practical value for the further application of glass bridge panels in engineering applications.

Keywords: bridge deck; experimental study; glass panel; wheel pressure position; wheel load

1 INTRODUCTION

In China, the scientific research on glass as a building material began in the late 1980s. At present, China has introduced and developed new types of glass, such as interlayer, tempered, ion exchange, glazed surface decoration and chemical thermal decomposition ones, which rapidly increases the application of glass in industrial and civil buildings and becomes the third largest building material except steel and concrete [1]. The load-bearing glass plate is usually made of tempered glass, which is a kind of prestressed glass after deep processing on the basis of ordinary glass, so as to improve the bearing capacity of the glass structure [2]. The beam, column and plate of glass were first used in building curtain wall, ceiling, corridor, stairs and other structures. Recently, due to light weight, high strength, good light transmittance, energy saving and environmental protection, etc., the beam, column and plate of glass have been applied in the bridge panel of pedestrian landscape bridge [3].

Different from traditional building structural materials, the strength of glass plate varies due to different load direction, load type, glass type and thickness [4, 5]. Glass strength of different batches has certain dispersion. The application of glass structural materials to bridge structural components needs to be cautious. In order to solve the stress and calculation of the glass bridge deck for pedestrian view, Wang Yuanqing [6, 7] analytical expression of the stress and deformation calculation of the simply supported slab with four sides under uniform load is given in literature. Wang Xun, Wang Yuanqing [8-10], the in-plane bending glass plate can be equivalent to simply supported or fixed supported plate beams on both sides, and it is pointed out that the bearing capacity of in-plane bending glass plate is related to its plate thickness, length-width ratio, span-depth ratio and height-span ratio, which increases with the increase of plate thickness, decreases with the increase of span-depth ratio, and increases with the increase of height-span-ratio. Therefore, a systematic calculation method has been developed for the pedestrian glass bridge panel. The glass bridge plate of truss beam can be approximately equivalent to the glass plate supported by frame. At present, the research work mainly focuses on the theoretical calculation of simple supported slab with four sides and one-way slab under uniform load. Zhang Yangmei [11] etc. Analysis of SGP laminated glass under impact test. Yin Yongwei [12] etc. examined whether the load-displacement and load-stress curves of point-supported hollow glass and laminated glass approached linearity with the increase of load; the calculated values of displacement and stress of point-supported hollow glass and laminated glass in current national regulations were larger than the experimental values and conservative. Paolo Forabosch [13], Mehmet Zulfu Asık [14] proposed a mathematical model of the stress prediction model for the new glass beam structure, Ruo-Qiang Feng [15] glass cable truss beam test and finite element analysis, although the laminated armor glass has been broken. The truss still maintains its carrying capacity, and the remaining bearing capacity can be used as a safety reserve.

In bridge engineering, the load is vehicle wheel pressure, which is not equal to uniformly distributed load. The existing analytical expressions based on plate and shell theory cannot be applied. The application of glass plate to vehicular bridge deck is the first case, and relevant experimental research and theoretical analysis have not been seen yet. Less emphasis is placed on the persistence of load application. The author was fully involved in the design and comparison of the scheme of the bridge deck for the automobile channel of Xi'an Sanqiao international automobile parts port.

The mixture of glass bridge panel and concrete bridge panel instead of full concrete bridge panel can give full play to the transparency of glass materials and significantly reduce energy consumption, thus becoming the preferred solution. In order to explore the technical feasibility of applying glass bridge panel to vehicular bridge deck, this paper intends to carry out experimental research on the bearing capacity of glass bridge panel at different wheel pressure positions from the perspective of wheel pressure position, which is the easiest to reveal the mechanical characteristics of the vehicular bridge panel [16].

Car access is an important part of the car city project. The car passage is composed of multiple layers. If the car channel adopts the traditional bitumen concrete bridge deck, the car passages on each floor need to be equipped with special illumination equipment and ensure sufficient lighting time. This not only greatly increases the operating costs of the car city, but also causes huge waste of resources. In order to explore an environmentally-friendly lighting solution, it was finally decided to replace the full-concrete bridge deck with a mixture of glass bridge panels and concrete bridge decks, and to use natural light for the light transmission of glass materials. Since the glass bridge deck has been verified by design calculation and bearing capacity test, it has been widely applied to pedestrian bridges at home and abroad. Therefore, it is necessary to carry out the bearing capacity test under the normal use state and the ultimate bearing capacity of the glass bridge panel to verify whether the glass bridge panel meets the structural stress requirements of the automobile passage.

This paper mainly reveals the stress and displacement level of glass bridges under normal use conditions, and analyzes whether the strength and stiffness of the structure can meet the relevant requirements of current codes; it reveals the failure mode of glass bridge decks under the ultimate bearing capacity of glass structures and Carrying capacity.

2 TEST OVERVIEW

2.1 Determination and Simplification of Load

The Sanqiao international auto parts port is located in the western suburb of Xi'an, and its vehicle channel design is limited to small cars. According to statistics, the total weight of small cars generally does not exceed 30 kN, and the maximum weight of a single wheel is 7.5 kN. The contact surface between the tire and the ground is oval, which is processed as rectangle for the convenience of calculation. The greater the total weight of the car, the wider the tires, and the greater the area of contact with the ground. Through the investigation and statistics of the single wheel weight and contact area of small cars, the simulation effect and feasibility of test loading are comprehensively considered. The size of the contact surface of single wheel was taken as 200×100 mm, and the rubber pad with a thickness of 25 mm was used to simulate the effect of wheels.

2.2 Specimen Design

The maximum size of the glass plate used in the automobile passage of Xi'an Sanqiao international auto parts port is 102.5×130.0 cm. According to the mechanical characteristics of the glass plate, the design length and width of the specimen are determined to be 120×120 cm, and the thickness of the glass plate is 12 mm, as shown in Table 1. Glass plate specimens should meet the national standard "Safety Glass for Building - part 3: Laminated glass" (GB15763.3-2009), and the impact of shot bag should meet the requirements of class ii-1 laminated glass. The specimens shall meet the relevant requirements for floor glass in the "Technical Specification for Application of Building Glass" (JGJ113-2015), and shall be processed as follows: (1) Tempered glass must be homogeneously processed; (2) The edge of the specimen needs mechanical fine grinding and chamfering 5 mm width horizontal direction and 3mm thickness direction.

Table 1 Specimen design

Serial number	Glass type	Parameter	Specimen number	Quantity
1	Laminated glass	12 mm tempered glass + 1.56 mm PVB + 12 mm tempered glass + 1.56 mm PVB +12 mm tempered glass	JG001 - JG006	6
2	Single layer glass	12 mm tempered glass (same batch as laminated glass)	DJ001 - DJ003	3

2.3 Test Contents and Methods

The tempered glass used in engineering is generally sandwich glass, which is composed of a number of single layer tempered glass usually bonded by PVB or SGP film. The sandwich glass tested in this paper uses PVB film as the bonding material. There is no relevant data of the glass plate test under wheel load at home and abroad, and the influence of the position of the glass plate under wheel load on the failure mode and ultimate bearing capacity of the glass plate is analyzed. This paper intends to carry out experimental work from the following aspects: Consider comprehensively the stress characteristics of glass plate and the strength distribution characteristics of glass plate; In the test, the boundary condition is simply supported by four sides; The bearing capacity test of the wheel compression load located at the center, edge and corner of the plate was carried out using rubber pad of the same size to simulate the wheel action. In Tab. 2, JG represents laminated tempered glass and DG represents single tempered glass.

Table 2 Load position

Serial number	Load position	Specimen number
1	Center of glass plate	JG001, JG002, JG003, DJ001
2	Edge of glass plate	JG004, DJ002
3	Corner of glass panel	JG005, JG006, DJ003

Monotone graded loading is adopted. Firstly, load control is adopted and graded loading is added to 70% of the estimated ultimate load. Then, displacement loading is adopted and data collection is encrypted appropriately to get a smoother curve. When the load drops to 95% of the peak value, the test stops loading, and the maximum load in the loading process was taken as the ultimate bearing capacity of the specimen until the glass was destroyed. The failure mode, ultimate load and ultimate strain of the laminated glass JG001-JG006 and the single-layer glass DG001-DG003 were recorded respectively.

3 TEST LOADING AND TEST POINT LAYOUT

3.1 Test Equipment

The test loading was carried out by 100 kN pressure testing machine of Shaanxi bridge structure laboratory, highway college, Chang'an university. In the test, the displacement sensor was used to measure the deformation of the glass plate, and the strain gauge was used to test the rule of strain change on the surface of the glass plate. Japan TDS-302 static data acquisition instrument was used for displacement and strain data acquisition and testing, as shown in Fig. 1 and Fig. 2 below.

Figure 1 The full view of the test loading model

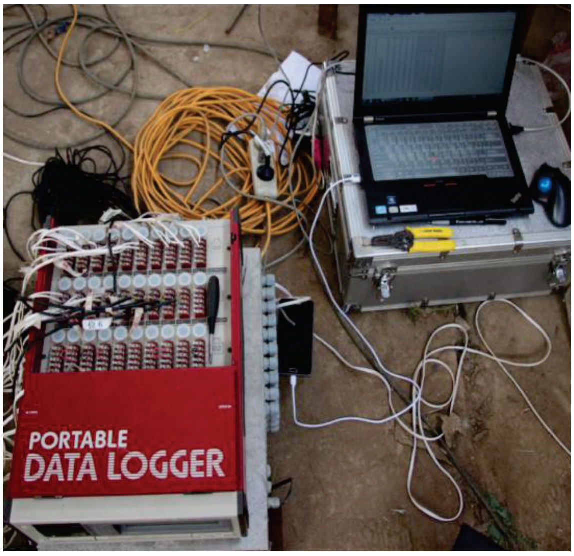
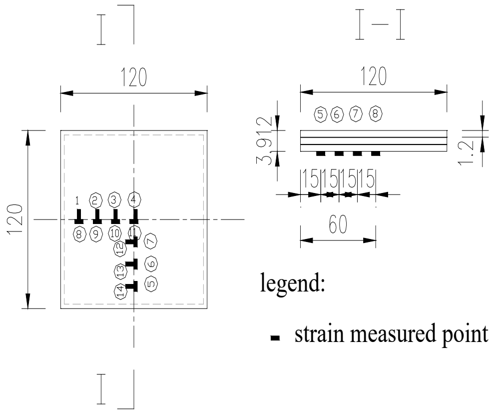


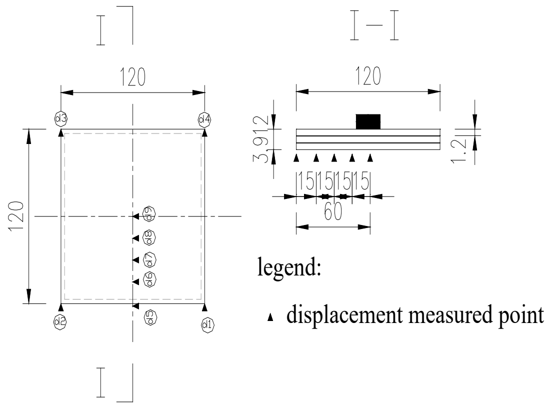
Figure 2 Test data acquisition equipment

3.2 TEST POINTS

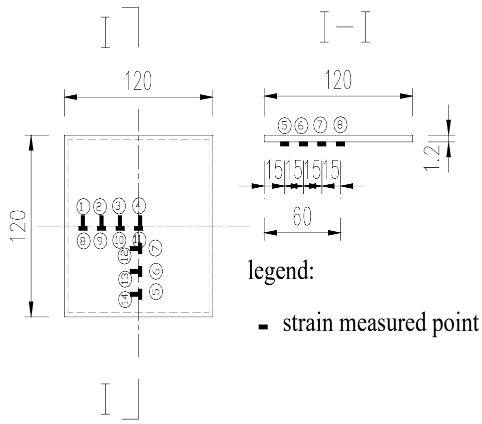
In order to analyze the stress distribution and Poisson's ratio along the length and width of the glass plate under wheel load, 4 rows of strain gauges were arranged at equal intervals along the length and width of the glass plate, as shown in Fig. 3a and Fig. 3c. In the test, the displacement sensor was used to measure the deformation of the glass plate, and the strain gauge was used to test the rule of strain change on the surface of the glass plate. Arrangement of measuring points in displacement and strain is as shown in Fig. 3, the test temperature under normal temperature (25 °C).



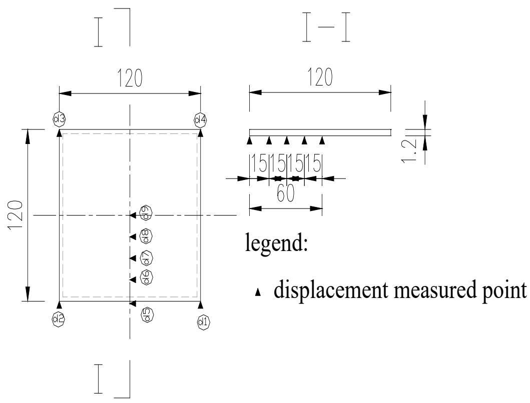
(a) Arrangement of strain measuring points of laminate glass



(b) Arrangement of displacement measuring points of laminate glass



(c) Arrangement of strain measuring points of single-layer glass

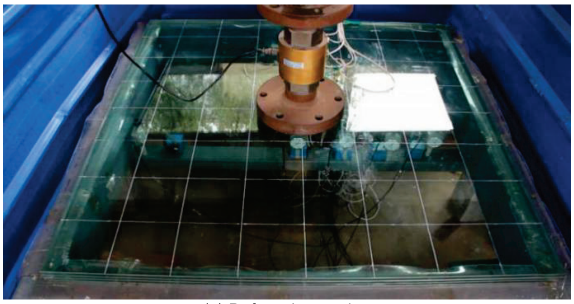


(d) Arrangement of displacement measuring points of single-layer glass
Figure 3 Survey point arrangement

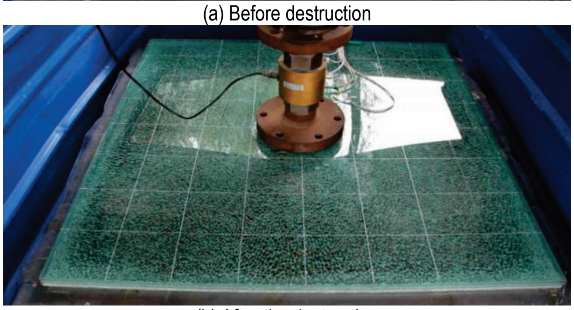
4 TEST RESULTS AND ANALYSIS

4.1 The Load Acting on the Center of the Plate

The test group with load located in the center of the plate includes 3 laminated glasses and 1 single glass. The laminated glass specimens were numbered JG001, JG002 and JG003 respectively, and the single-layer glass specimens were numbered DG001.



(a) Before destruction

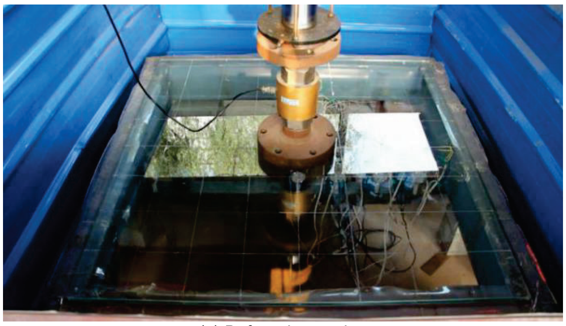


(b) After the destruction

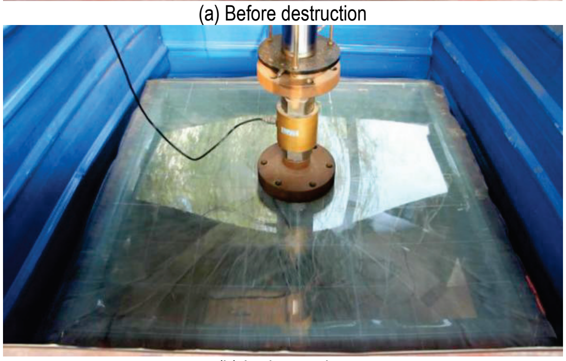
(c) After the destruction

Figure 4 Laminated glass failure form

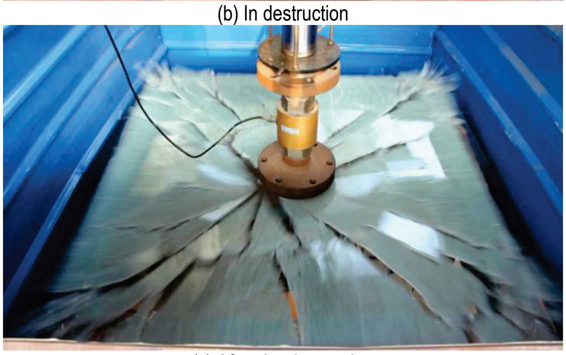
The stress and failure modes of the specimen are shown in Fig. 4 and Fig. 5 respectively. As can be seen from Fig. 4, when the laminated glass specimens JG001, JG002 and JG003 reached the ultimate load, a sound of "hum" appears. The bottom layer of glass was destroyed instantaneously. There were only a few pieces of broken glass slag on the ground, but they were all less than 1cm, and there were fine cracks at the stress point, while the rest showed large area network cracks (Fig. 4c). As can be seen from Fig. 5, when the single-layer glass specimen DG001 reached the ultimate load, there was a sound of "pa", which is obviously larger than that of the sandwich glass. The glass plate was cracked and broken within 1/24 of a second (Fig. 5c). After the glass was broken, most of the pieces were cubic, with a length and width of about 2-5 cm.



(a) Before destruction



(b) In destruction



(c) After the destruction

(d) After the destruction

Figure 5 Single layer glass failure form

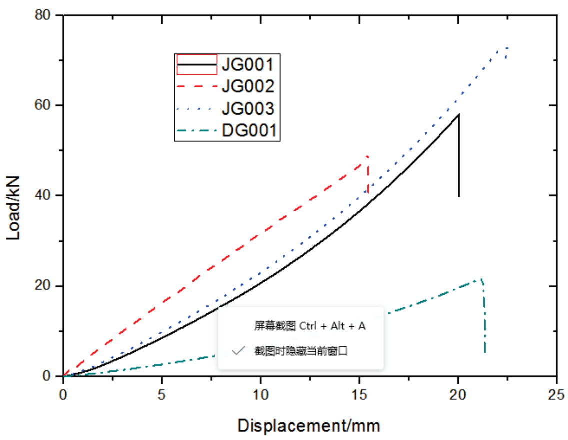
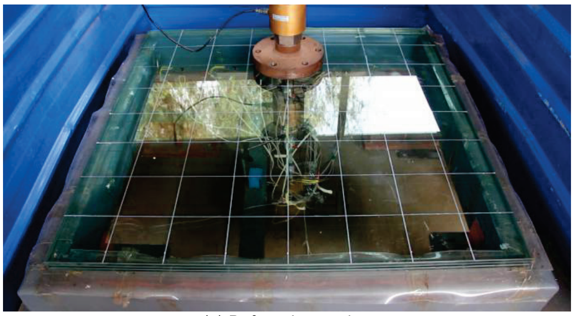


Figure 6 Load-displacement curves

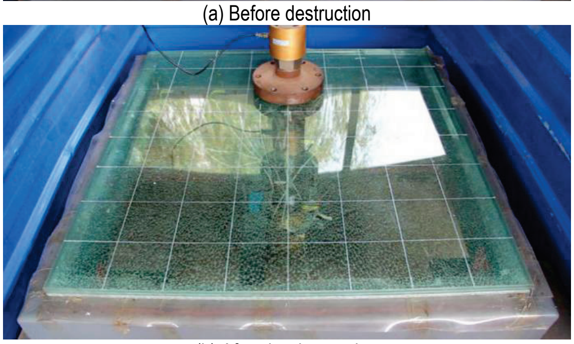
Fig. 6 shows the load-displacement curve when the wheel load is located at the center of the glass plate. The load before the destruction of the glass plate is taken as the ultimate bearing capacity of the structure. The ultimate bearing capacity of sandwich glass is 49.6 kN, 58.5 kN and 72.1 kN, respectively. The mean value of the three is 60.1kN, and the ultimate bearing capacity of single-layer glass is 21.6 kN.

4.2 The Load Acting on the Plate Edge

The wheel load test group located at the plate edge consists of one laminated glass and one single glass. The laminated glass specimens were numbered JG004, and the single-layer glass specimens were numbered DG002.



(a) Before destruction

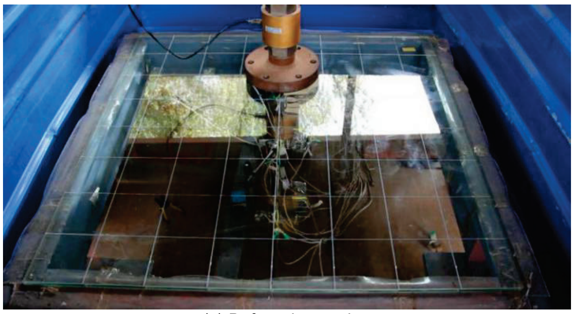


(b) After the destruction

Figure 7 Laminated glass failure form

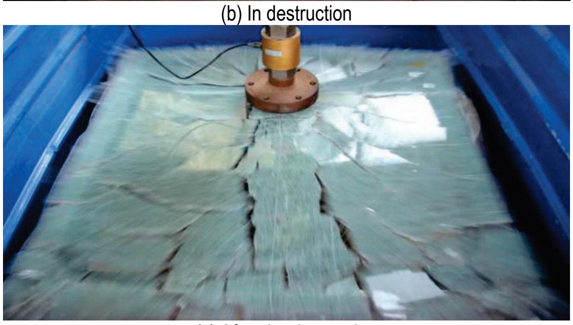
The failure modes of the specimens are shown in Fig. 7 and Fig. 8 respectively. As can be seen from Fig. 7, after the ultimate load of the sandwich glass specimen JG004 was reached, there was a sound of "hum", and the bottom glass was destroyed instantly. There were only a few pieces of broken glass slag on the ground, but they were all less than 1cm. As can be seen from Fig. 8, when the single-layer glass specimen DG002 reached the ultimate load, the sound of "crack" appeared, which was obviously larger than that of the sandwich glass. The glass plate was cracked and broken within 1/24 of a second. After the glass was broken, most of the pieces were cubic, with the length and width of about 2-5 cm.

Fig. 9 shows the load-displacement curve of the glass plate. It can be seen from the figure that the ultimate bearing capacity of the sandwich glass is 59.0 kN and that of the single-layer glass is 17.0 kN.

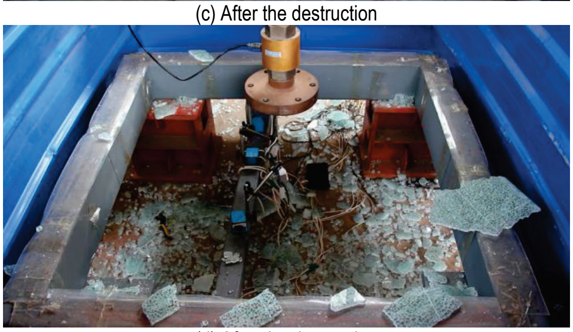


(a) Before destruction

(b) In destruction



(c) After the destruction



(d) After the destruction

Figure 8 Single layer glass failure form

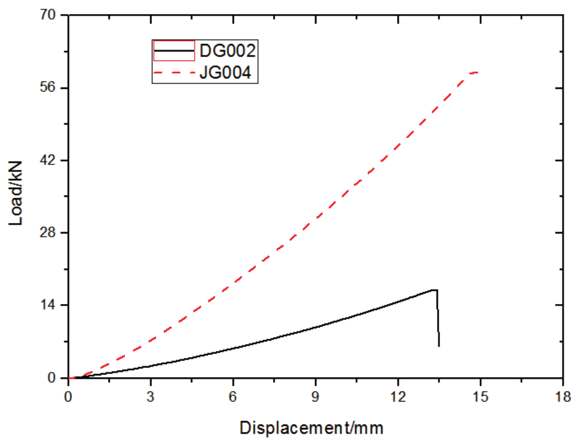
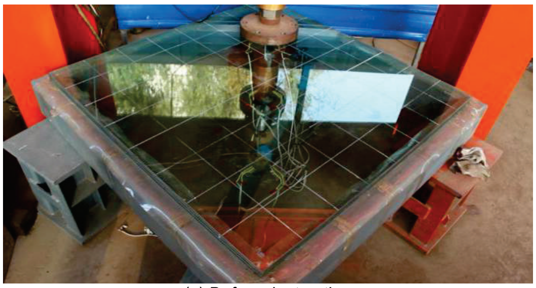


Figure 9 Load-displacement curves

4.3 The Load Acting on the Corner of the Plate

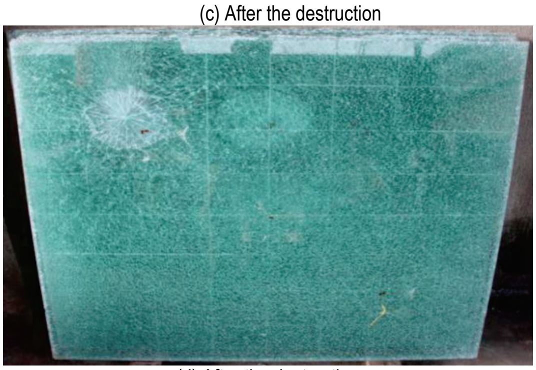
The test group, where the wheel load is located at the corner of the plate, consists of two laminated glasses and one single glass. The laminated glass specimen numbers are JG005 and JG006 respectively, and the single-layer glass specimen number is DG003.



(a) Before destruction

(b) In destruction

(c) After the destruction

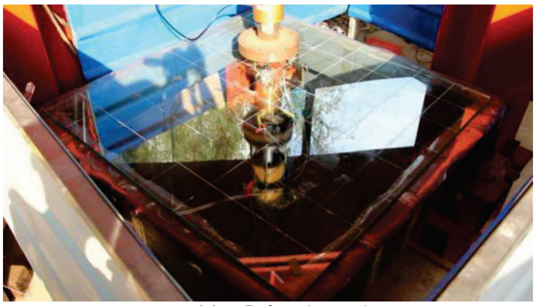


(d) After the destruction

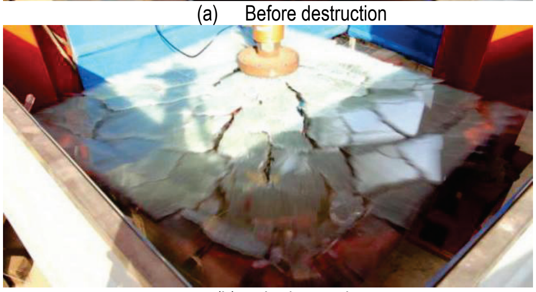
Figure 10 Laminated glass failure form

The failure modes of various specimens are shown in Fig. 10 and Fig. 11 respectively. As can be seen from Fig. 10, when the ultimate loads of the sandwich glass specimens JG005 and JG006 were reached, there was a sound of "hum", and the bottom glass was destroyed instantly. There were only a few pieces of broken glass slag on the ground, but they were all less than 1cm. As can be seen from Fig. 11, when the single-layer glass specimen DG003 reached the ultimate load, the sound of "crack" appeared, which was obviously larger than that of the sandwich glass. The glass plate was cracked and broken within 1/24 of a second. After the glass was broken, most of the broken pieces were in the form of cubes, with the length and width of about 2-5 cm.

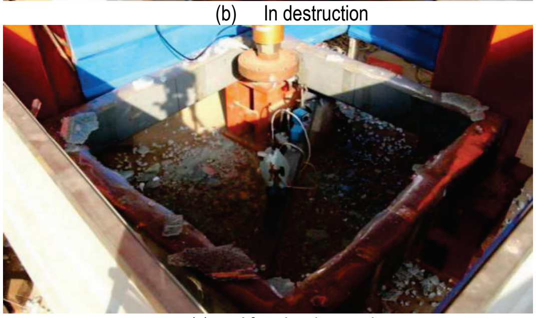
Fig. 12 shows the load-displacement curve of the glass plate. It can be seen from the figure that the ultimate bearing capacity of sandwich glass is 51.9 kN and 51.2 kN respectively, and the ultimate bearing capacity of single-layer glass is 14.1 kN.



(a) Before destruction



(b) In destruction



(c) After the destruction

Figure 11 Single layer glass failure form

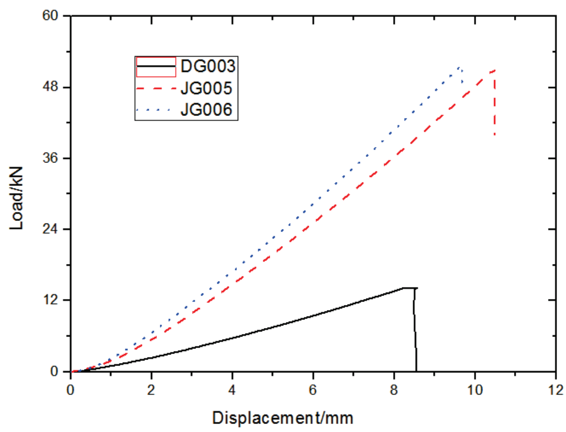


Figure 12 Load-displacement curves

4.4 Test Results

The failure modes of sandwich glass and monolayer glass are similar, with the wheel load acting on the center, edge or corner of the plate. The four corners of the glass plate were obviously upturned before the failure of the single-layer glass specimen, but no crack or visible damage was found. The destruction process was very rapid. According to the speed recorded by the camera, the destruction process was completed within 1/24 of a second, and the glass cracked instantaneously. The cracks were spread all over the board surface and shot around rapidly. The glass fragment in the corner of the plate flew out at a distance of nearly 5 meters, while the glass fragment in the middle of the plate flew out at a relatively small distance. After the destruction, the glass plate as a whole was seriously broken, and the glass fragments were basically kept at an obtuse Angle, greatly reducing the degree of personal injury. Before the laminated glass was destroyed, the four corners of the glass plate were slightly upturned, but no crack or visible damage was found. The destruction process was very rapid, and the glass plate at the bottom of the three-layer glass plate immediately cracked, with the cracks throughout the whole glass. No glass fragments flew out when the bottom glass was broken, and only fine glass fragments fell off.

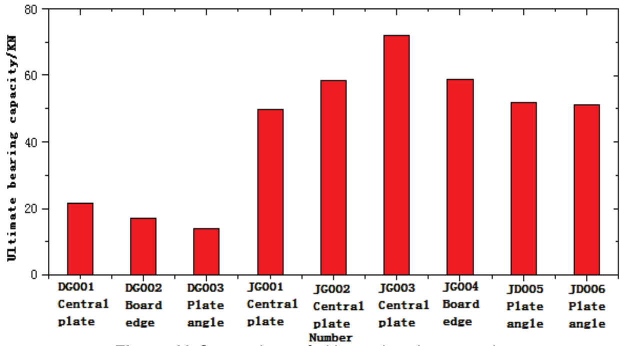


Figure 13 Comparison of ultimate bearing capacity

From the perspective of ultimate bearing capacity, the load in the center, at the edge or corner of the plate significantly affects the ultimate bearing capacity of the glass plate. The comparison results are shown in Fig. 13. It can be seen from Fig. 13 that the ultimate bearing capacity of single-layer glass under different load positions is in the order of plate middle, plate edge and plate angle from large to small and the sandwich glass conforms to the same rule. The ratio of bearing capacity of plate edge, plate angle and plate center of single layer glass under load is 78.7% and 64.8%, respectively. The ratio of bearing capacity of plate edge, plate angle and center of sandwich glass under load is 98.3% and 86.5%, respectively. For laminated glass, the effect of load position on the ultimate bearing capacity of glass plate is weaker than that of single glass. From the perspective of structural stiffness, the maximum deformation appears at the center of the plate under the load of wheel load, followed by the load on the edge of the plate, and the minimum deformation appears at the corner of the plate.

5 CONCLUSION

In this paper, laminated glass and single-layer glass are used as test objects, and the bearing capacity test applied to different positions of the glass panel by simulating the concentrated force of the wheel is tested. When the wheel load acts on the central position of the single-layer glass plate and the sandwich glass plate, the deformation of the plate is the largest; when it acts on the corner of the glass plate, the stress of the plate is the largest; and the influence on the plate edge is in the middle. The test results in this paper can be of practical value for further application of glass bridge panels in engineering applications.

The ultimate bearing capacity under wheel load acting on the center, side and corner of the laminated glass plate is 2.78, 3.47 and 3.66 times that of the single-layer glass plate at the same position.

The ratio of bearing capacity of plate edge, plate angle and plate center of single layer glass under load is 78.7% and 64.8%, respectively. The ratio of bearing capacity of plate edge, plate angle and center of sandwich glass under load is 98.3% and 86.5%, respectively.

The bearing capacity of two layers of PVB and three layers of tempered glass is 3 times better than that of the single layer steel glass with the same material. The load-displacement change curves of laminated glass and single-layer glass at different locations under the load of wheel compression are linear.

In the future, the glass bridge panel can enrich the architectural design, increase the natural lighting of the building, and achieve the goal of environmental protection and energy conservation. However, due to the characteristics of the material of the glass itself, there will be many mechanical properties researches to be applied to the structure in the next step. Due to the brittleness of the glass structure, it is more strictly managed than other materials in terms of storage, installation and protection.

Acknowledgements

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