Calculation of Equivalent Uniform Live Load of the Floor in Bus Garage

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Abstract. According to the overview of equivalent load calculation of the two-way slab in Appendix C in Load Code for the Design of Building Structures (GB50009-2012), this paper introduces the calculation method of the equivalent uniform live load on the two-way slab in engineering design, providing calculation data for the subsequent force analysis of the whole structure using computer software.

Keywords: Bus garage, equivalent floor load, bus wheel pressure.

1. Introduction

With the development of urbanization, a growing number of cities are vigorously promoting the public traffic system to alleviate the increasing traffic pressure. At present, various bus garages are designed to improve the system. However, since the workshop of the previous bus garage was on one floor and the load for bus maintenance was directly transferred to the ground, there are few calculations for the floor load in the bus garage. In vehicle maintenance shops for bus shut-down maintenance and other items, since the production, overhauling and other technical requirements and the structural layout are different, the floor live loads differ greatly, the calculation of the structural force using the influence line is complicated and requires high workload. Therefore, the “equivalent uniform live load” is often used for the overall structural calculation. The “equivalent uniform live load” is that we should find a full uniform live load value which has an equivalent effect on the floor to the known concentrated load (or local load). The equivalent here means that the maximum bending moment values generated are the same. The equivalent uniform live load is used to deal with different local live loads, so that it has a similar effect on the structure to the local loads in actual use [1]. For the calculation of the equivalent uniform live load of the floor, the basic algorithm is given in the Load Code for the Design of Building Structures. However, the calculation method for equivalent bending moment values and two-way slabs is not specified. In this paper, we will calculate the equivalent uniform live load of the floor in the bus garage according to the actual project and the Load Code for the Design of Building Structures, and provide the reference value, thus providing effective reference for the calculation of equivalent loads in the bus garage.

2. Requirements in Load Code for the Design of Building Structures for the floor load in the parking garage

According to Article 5.1.1 (8) in the Load Code for the Design of Building Structures GB 50009--2012 (hereinafter referred to as the Load Code), the current code in China, for “one-way slabs with a span of not less than 2 m” and “two-way slabs with a span of not less than 3 m × 3 m”, the standard value of the bus load is 4.0 kN/m2; for “two-way slabs with a span of not less than 6 m × 6 m”, the standard value of the bus load is 2.5 kN/m2. This article is enforceable. Meanwhile, we can see that this article is otherwise stated in Note 3: the bus live load in Article 5.1.1 (8) applies only to buses carrying fewer than 9 passengers; when failing to meet the requirements in this table, the local load of the wheel should be converted into the equivalent uniform live load by the principle of structural effect equivalence. Therefore, we should not simply use 4.0 kN/m2 or 2.5 kN/m2 as the value of the floor live load in the bus garage. Instead, we should consider the local load with the maximum bus wheel pressure according to the layout of buses; values for the equivalent uniform live loads of one-way slabs or two-way slabs with different spans are also different. For a bus with small wheel track, the interaction between two wheels should be considered.

The calculation of the equivalent floor live load is stipulated in Appendix C in the Load Code: C.0.1 "the equivalent uniform live load of the floor should be determined on the design control position according to the equivalence of deformation and crack caused by internal forces (such as bending moment and shearing force). In general, it can be determined only by the equivalence of internal forces" [2]. For slabs, we have specified that such equivalence refers exclusively to the same "bending moment".

3. Bus specifications and slab size

In this paper, the actual data used in a bus garage in Fengtai District of Beijing are used for calculation. Parking areas are shown in Fig. 1. Areas between L-axis to R-axis are parking and maintenance areas for buses, and buses can only run in one direction in a straight line, and only one row of buses is allowed within a span of 7 500 mm. In this way, the load can be calculated more clearly.

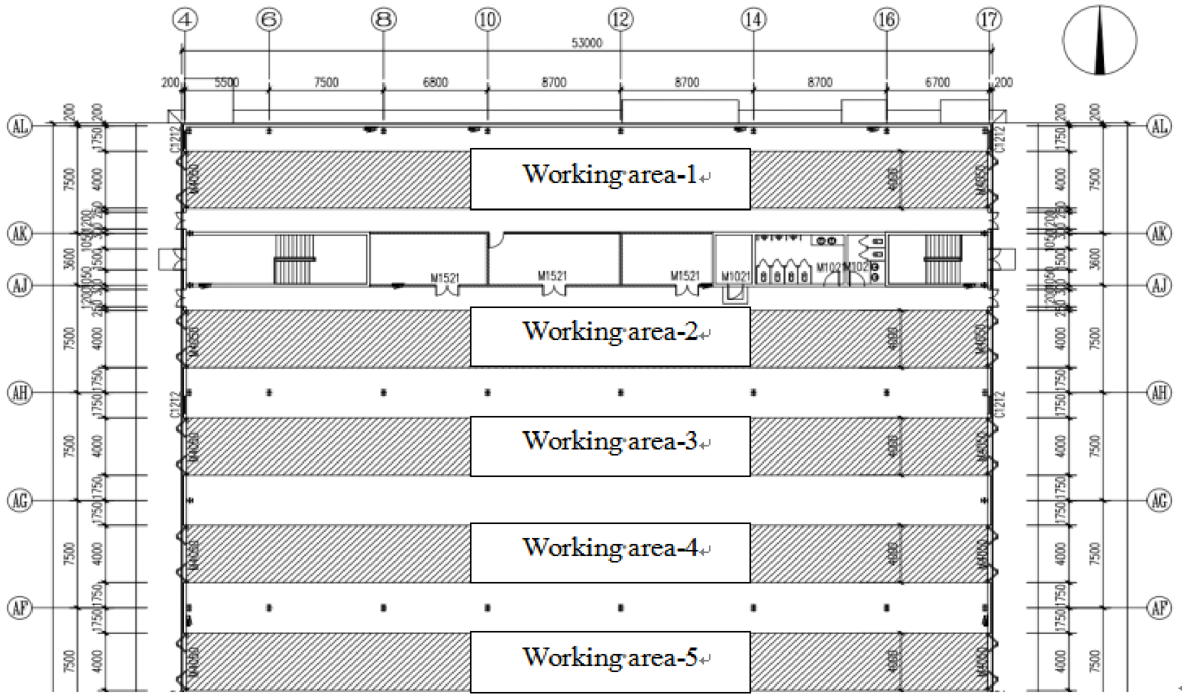

Figure 1. Floor plan of bus garage

No.	Vehicle length	Uniaxial weight (Kg)	Biaxial weight (Kg)	Triaxial weight (Kg)	Total mass (Kg)	Front track (mm)	Mid track (mm)	Rear (servo) track (mm)	Front-mid wheel base (mm)	Mid-rear wheel base (mm)	Front-rear wheel base (mm)
1	6m	1700	4900	/	6600	1750	/	1530	/	/	3200
2	8. 5m	2972	5935	/	8907	2025	/	1810	/	/	4000
3	12m double dock	3575	11044	5581	20200	2160	1860	2096	5600	1470	/
4	12m single	3610	8890	/	12500	2101	/	1836	/	/	6100
5	14 m single	4120	7660	3880	15660	2156	1860	2082	6150	1450	/
6	16 m lane	5140	4060	9330	18530	2156	1890	1860	5000	5700	/
7	18 m lane	4060	3668	9674	17402	2156	1890	1860	5800	6100	/

Figure 2. Statistics of axle weight and wheel base of different vehicle models

The bus garage provides the vehicle models for parking and vehicle-related data (Fig. 2)

Considering the driving uncertainty in each lane, we calculate using a bus with a maximum length of 18 meters, with 5.8 m between front and mid axles and 6.1 m between mid and rear axles. There is one wheel on each side of the front axle, with the size of 0.2 m*0.2 m on the ground, and two wheels on each side of the mid and rear axles, with the size of 0.2 m*0.6 m on the ground. The front track is 2.156 m, the mid track is 1.890 m, and the rear track is 1.860 m. The front axle weight is 4 060 kg, the mid axle weight is 3 668 kg, and the rear axle weight is 9 674 kg, totaling 17 402 kg. According to the JGJ100-2015 Code for Design of Parking Garage Building, the minimum distance between adjacent buses should be 2.4 m longitudinally when parking, as shown in Fig. 3.

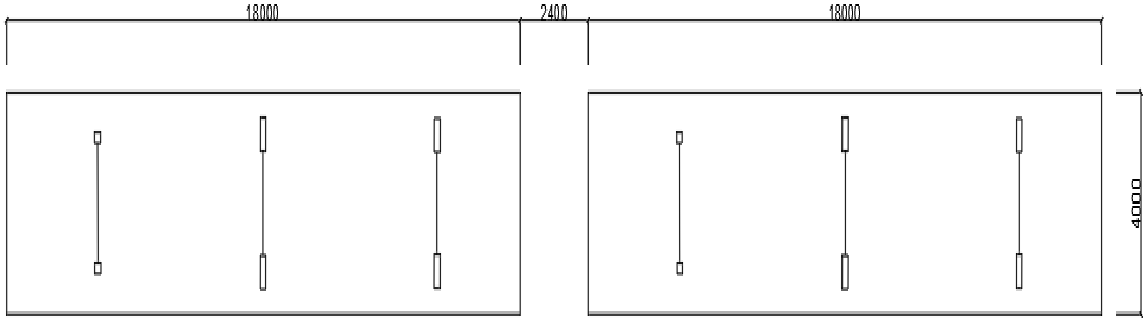

Figure 3. Plan view size of buses

Primary and secondary beams are used in the structural design (Fig. 4). However, according to the impact resistance design of buses, the slab is 250 mm in thickness, while the secondary beam is only 250 × 500 mm in the sectional dimension and is of insufficient stiffness and bearing capacity; in addition, the floor has 100 mm thick cushions after the completion of the slabs. Therefore, secondary beams are used as the ribbed stiffeners of the slab and the main frame beam + thick slab structure is designed.

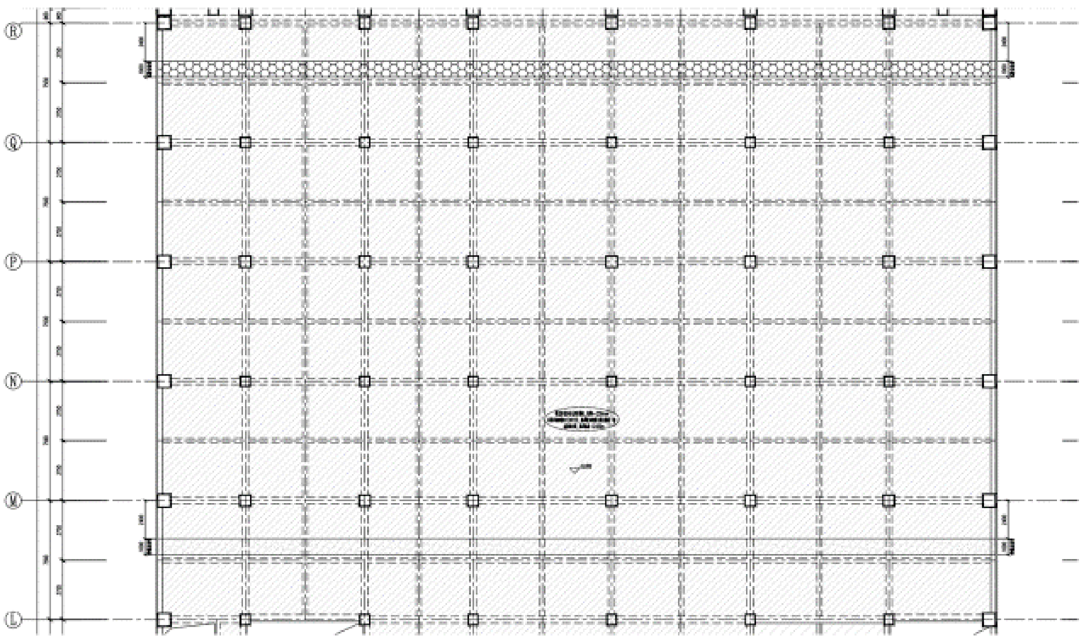

Figure 4. Structural layout plan of the floor

4. Calculation method of equivalent uniform live load

4.1. Calculation based on one-way slab and uniaxial single wheel

According to the Load Code, the equivalent uniform live load q_e of local loads (including concentrated loads) on the one-way slab can be calculated by the following formula:

$$q_e = \frac{8M_{max}}{bl^2}$$

Where,
l-- Span of the slab;
b-- Effective distribution width of loads on the slab;
M_{max}-- Absolute maximum bending moment of simply supported one-way slab

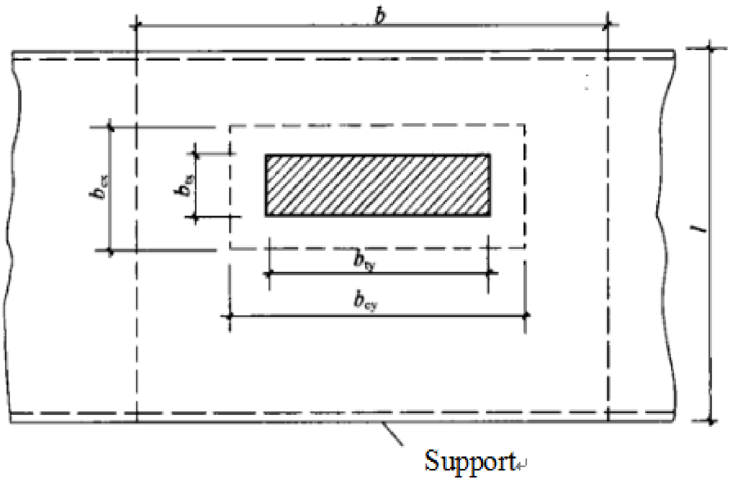

Figure 5. Effective distribution width of local loads on the simply supported slab

When the long side of the acting surface of the local loads is perpendicular to the span of the slab, and its length is less than or equal to 2.2 times the span of the slab, the effective distribution width b of local loads on the simply supported slab is:

$$b = \frac{2}{3}b_{cy} + 0.73l$$

Where,
l-- Span of the slab;
b_{cy}-- The calculated width of the acting surface of the loads perpendicular to the slab, and its value is $b_{cy} = b_{ty} + 2s + h$, where b_{ty} is the width of the acting surface of the loads is perpendicular to the span of the slab, s is the thickness of the cushion, and h is the thickness of the slab.

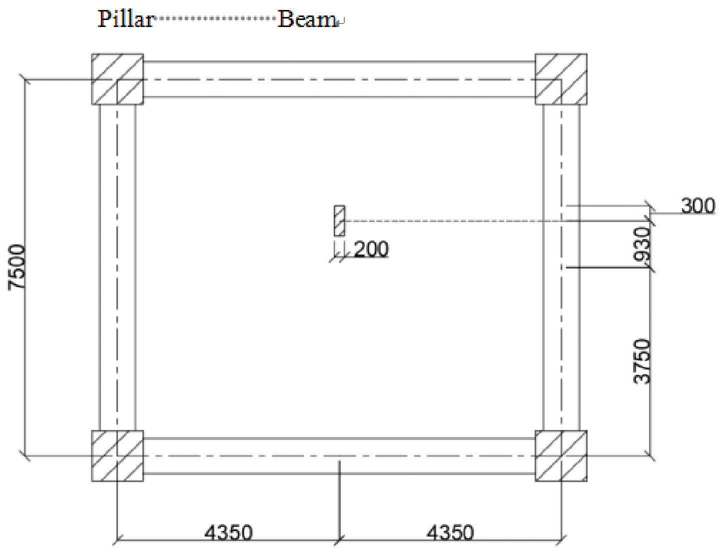

Figure 6. Distribution of actual loads under single-wheel loads

We calculate that b = 2/3*(0.6 + 2*0.1 + 0.25) + 0.73*8.7 = 7.051 m. Since b/2 is greater than the distance d between the loads on the tire and the slab edge, the effective distribution width b of the loads should be reduced, and the result is $b/2 + d$ = 6.046 m, q_e = (8*1/4*48.37*8.7)/6.046*8.7^2 = 1.84 kn/m^2

4.2. Calculation based on one-way slab and uniaxial dual wheel

According to the Load Code, when two local loads are adjacent with e < b, the effective distribution width of the loads should be reduced and can be calculated by the following formula:

$$b' = \frac{b}{2} + \frac{e}{2}$$

Where, e-- Distance between centers of two adjacent local loads.

Therefore, when the interaction between two tires is considered, the effective distribution width of loads is b’ = 7.051/2 + 1.86/2 = 4.456 m

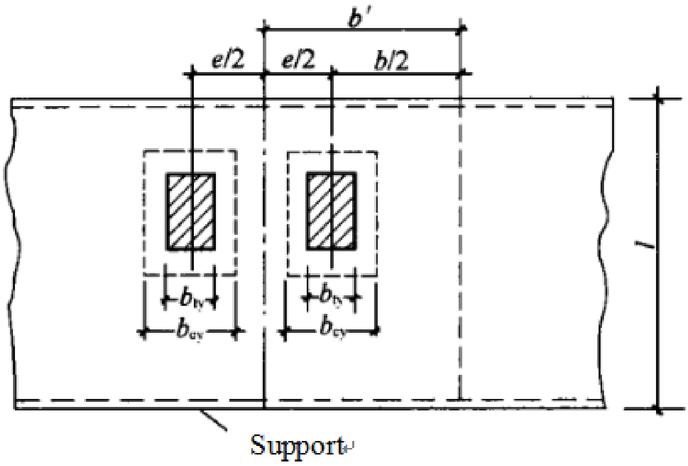

Figure 7. Effective distribution width of two adjacent local loads

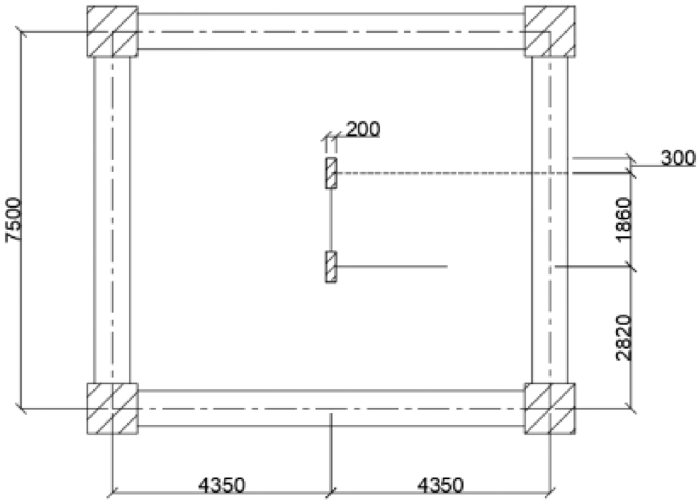

Figure 8. Distribution of actual loads under dual-wheel loads

When calculating the maximum bending moment, we can assume that the displacement of slabs is linear, and the displacement at the P1 point is 1, then we can deduce the displacement at the P2 point under the action of P1 according to Fig. 6.

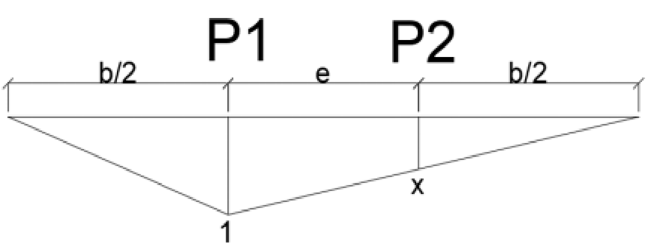

Figure 9. Displacement influence line of slabs under the action of P1

We can calculate that the displacement X at the P2 point is $\frac{b/2}{\frac{b}{2}+e}$ = 0.655, and the bending moment at the P2 point can be calculated according to P = P1X + P2. P1 and P2 are of the same size and direction, so we only calculate the bending moment at the P2 point here and that at the P1 point can be calculated in the same way. At this moment, the maximum bending moment is M_{max} = 2.13* (48.37 + 0.655*48.37) = 170.5 kn·m. Since the distances d between the tire loads on both sides and the slab edge are less than b/2, it can be considered that the whole slab is under the action of the loads, namely the effective distribution width is b = 7.5 m, and the equivalent uniform live load is $\frac{8\times 170.5}{7.5\times 8.7^2}$ = 2.40 kn/m2.

5. Conclusion

According to the differences in equivalent uniform live load values of the floor in the bus garage obtained under the uniaxial single-wheel and uniaxial dual-wheel loads, the following conclusions can be drawn:

(1) The wheel load cannot directly act on the whole slab, the distribution width of the load changes with the change in the length of the acting surface and the thickness of the slab and will not exceed the edge of the slab;

(2) The calculation of the uniaxial dual-wheel load is not simply adding up two single-wheel loads. Instead, the overlap of the effective distribution width between the two loads should be considered and reduced, and the effect of one load on the bending moment at the acting position of the other load should also be considered;

(3) If the punching resistance capacity of the slab is not considered, and the maintenance load for buses running in one direction within a span is less than that in Article 5.1.1 in the Load Code, the floor load value can be selected according to the Load Code.

In the calculation of the equivalent uniform live load of the floor in the bus garage, the layout of local loads should be comprehensively considered, and the accurate simplified model and reasonable methods should be used. The load value is the key to the structural design, and the main basis for the subsequent design. Thus, we must correctly understand the equivalent floor load in structural design rather than mechanically copy the value, in case the structural design become unrealistic and meaningless.

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