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Experimental Study on Influence of Bearing Capacity of the Shallow Buried Structure with the Spring-Settlement Support under Blast Action

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Abstract: In order to find effective method to decrease the dynamic effect, the arched structure with the spring-settlement support was designed. The parameters such as pressure, strain and displacement was determined to investigate the influence of the shallow-buried and the spring-settlement supported structure's bearing capacity under the dynamic loading. Experiment showed that the bearing capacity of the shallow-buried structure with the spring-settlement support was much enhanced as compared with conventional support under the dynamic loading. Experiment also proved that how much in a degree the spring- settlement support influence the bearing capacity is relative to spring's rigidity.

Keywords: Bearing capacity, experiment, mechanics of explosion, spring-settlement support

INTRODUCTION

Found in engineering practice, when the foundation subsides, the shallow buried structure acted by dynamic load can withstand more load than expected. In the chemical explosion experiment, we often found that the structure in soft foundation happened different degree of subsidence and the measurement parameters such as the internal force were often less than theory predicted value. It can be said that although action time of the dynamic load produced by explosion is short, but the structure in soft foundation has the function of reducing the effect of dynamic load.

In the protection engineering, many domestic and foreign scholars have done a lot of research study to reduce the effect of dynamic load acted on the structural. Some engineering measures have played a positive role to improve the resistance of structure, such as setting barrier bomb layer to make the incoming weapons to explode at a safe distance and setting air isolation layer to influence the propagation of pressure wave. But the research using the measures of the structure itself to improve the structure resistance is still in the theory discussion stage.

From 1966 to 1975, Hsu (1966, 1967, 1968a, b) published a series of papers, which solved the dynamic stability problems with di1erent boundary conditions and the subject of impulsion and step loads analytically. Lock (1966) and Lock *et al*. (1968) provided the numerical analysis of sti1ness supporting shallow arch and shallow done based on the Budiansky-Routh stability criterion and corresponding experimental results. Lo (1976) solved this problem by using the method of integration equation. Johnson (1978, 1980) studied the response and the e1ect of damping on dynamic snap-through of a shallow circle arch. Kounadis *et al*. (1989) provided the results for dynamic buckling of an arch model under impact loading. In the last 90 years, the theoretical and experimental works on non-linear dynamic response, dynamic behavior and global dynamic stability of shallow arch (Blair *et al*., 1996; Patricio *et al*., 1998; Levitas *et al*., 1997) and the experimental study on regular and irregular motions of shallow arch with elastic supports (Jianxue and Zhenmao, 1990) have been reported independently. Yan *et al*. (2003) studied the dynamic response of the beam with elastic supporting and torsional constraint and pointed out that compared with the rigid support; the effect of the elastic support can reduced the vibration frequency and coefficient of the dynamic load of the beam. Fang and Du (2006) analyzed the displacement of the elastic and damping supporting beam under blast action and showed that the elastic and damping support can effectively improve the structure resistance. Song *et al*. (2007) studied the dynamic response of the beam with flexible dynamic boundary under blast action and the research showed that the dynamic boundary had a great influence on the beam's deformation and stress. Compared with the rigid support, the vertical elastic support can make the amplitude of the beam's internal force to decrease with the action of the short time dynamic load and to reduce the frequency of the beam's vibration; vertical damping support can make the structure's internal force and

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(a) Spring-settlement support structure

(b) Normal support structure

Fig. 1: Spring-settlement support and normal support under arched steel-pipe skeleton

relative displacement to decay gradually as time. The elastic supporting can improve the structure resistance. Elastic support can produce the larger settlement in the dynamic loads to expand the influence of the load on the structure. Researching the dynamic response problem of elastic supporting structure has important significance to improve structure antiknock ability and design protective structure. However the above documents almost studied the simplified elastic supporting structure from theoretical or numerical method and few researchers did it from experimental method. This study treated the small span arch structure of spring support as the research object, through the chemical explosion experiment of shallow buried structure, to inspection the unloading effect of spring support structure, so as to explore the mechanism and structure measures to decrease the effect of the dynamic loads.

EXPERIMENTAL SETUP

The experiment was designed including the following two forms: the spring support structure and the conventional support structure (Fig. 1) and the dynamic and static load stress diagram under the condition of shallow buried was shown in Fig. 2.

Spring settlement support used the vertical spring structure and we designed and processed the spring (Fig. 3) whose stiffness coefficient is K = 100 kN/m according to the static load and designed dynamic load acted on the structure. The compression deformation value of the spring caused by static load is about 1/3 of the maximum compression deformation value. The mainly compressive deformation was caused by dynamic load and the maximum deflection is about 100

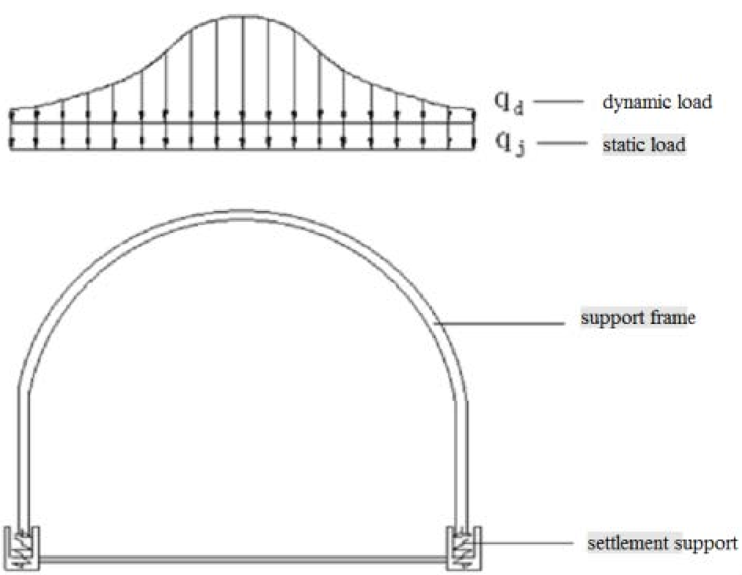


Fig. 2: Key diagram of structure with spring - settlement support

Fig. 3: Spring-settlement (K = 100kN/m) mm

The static load calibration showed that the spring compression displacement is consistent in step load compression process and its performance is relatively stable, so it conformed to the experimental requirement. The conventional support had no settlement mechanism, so that it was convenient to compare with the spring support structure.

Experimental support structure used skeleton type steel tube and the structural framework used the seamless steel tube of φ 50×3.5 mm. Test segment

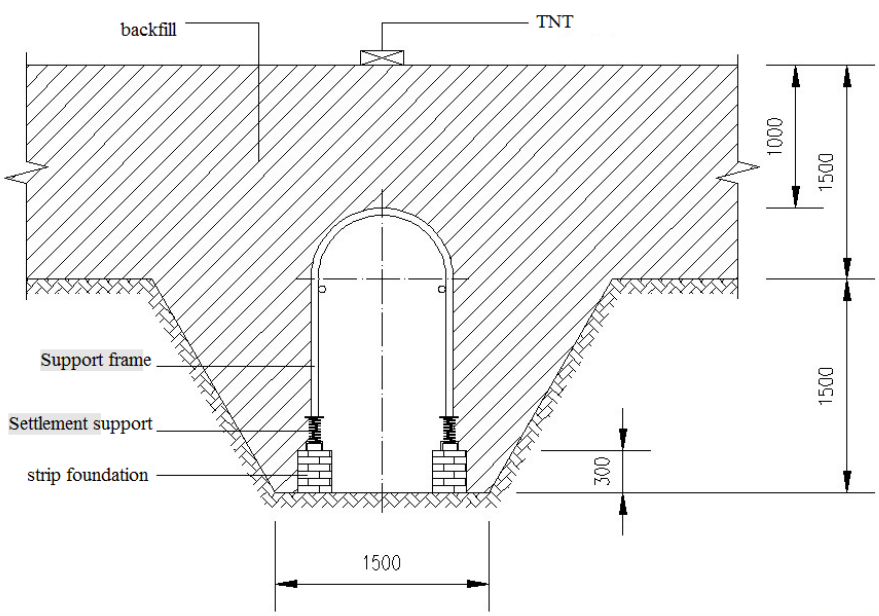


Fig. 4: Schematic diagram of the section of text structure and the loading set-up

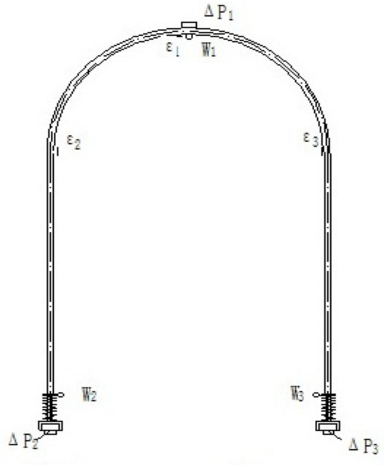


Fig. 5: Arrangement of measurement point

length 2.20 m, width 0.92 m, high 1.65 m and skeleton spacing 0.5 m. The construction of the experimental structure was shown in Fig. 4, excavation length 2.5 m, bottom width 1.5 m, depth1.5 m. Test member was set in the middle position of the experimental section. The position of the measuring point was shown in Fig. 5. The TST3000 dynamic test system was used for data acquisition. Dynamic loading was caused by the explosion on top of the test section. Four time's chemical explosion experiments were being done and the charge quantity was 1, 2, 3, 5 kg charge respectively and then measured and recorded every measuring point parameters.

EXPERIMENTAL RESULTS AND ANALYSIS

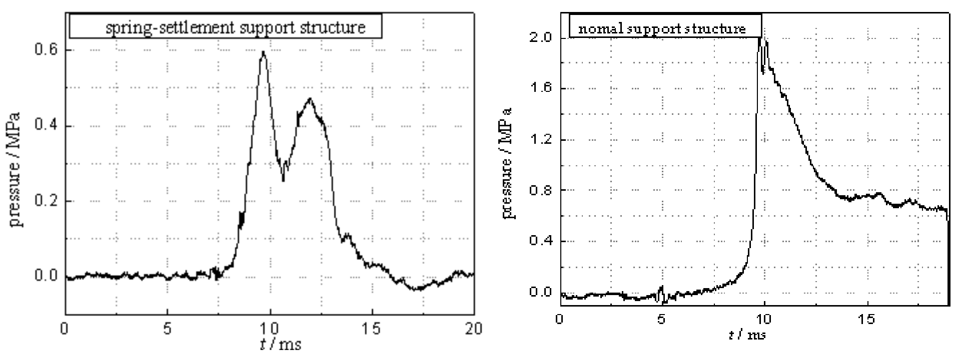
After each experiment the structure all don't appear obvious macroscopic deformation. When the charge weight is 5 kg, the major displacement value of spring support structure is 64 mm and plus the compression quantity 33 mm resulted by the soil static loading, then the total compressed volume of spring is 97 mm, which is close to the largest compressed volume of spring. All these show that the experiment settings are reasonable. Due to the symmetry of the structure, the results of the measuring point P3, ε 3 and P2, ε2 are basic the same. The date tested by the measuring point W3 is not listed in the table owing to instrument fault.

The time history curve of pressure, strain and displacement are showed in Fig. 6 to 8, when the charge weight is 5 kg both of the spring support structure and conventional support structure. From Fig. 6, we can see the measuring point pressure of the spring support structure reaches maximum at about10 ms and then decreases gradually. The measuring point pressure of conventional support structure has the same trend with the spring support structure.

From Fig. 7, we can seethe measuring point strain both of the spring support structure and conventional support structure reaches maximum at about20ms and then the measuring point's train of the spring support structure decreases gradually, but he measuring point's train of the conventional support structure remains unchanged. Figure 8 indicates that due to the damping effect of covering soil and structure itself, the node at the top of arch structure is a vibration form in the chemical explosion loads, but the former returns to the starting position after vibration, while the latter produces permanent vertical displacement about 20 mm, because of the whole displacement of the structure and the unrecoverable deformation resulted from structure itself.

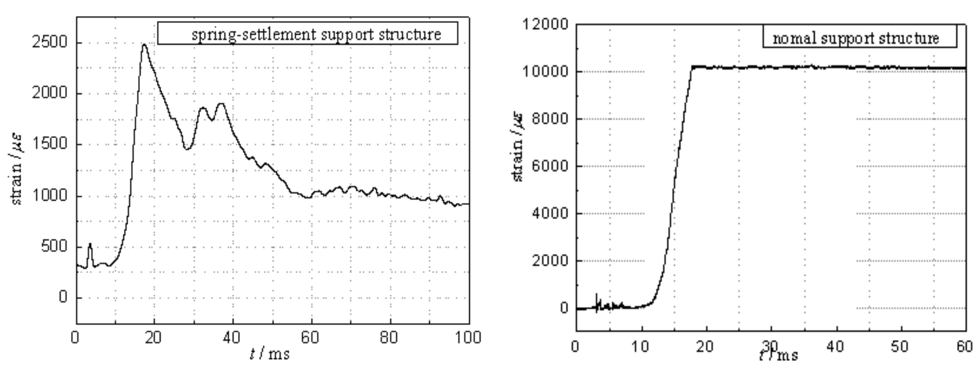
The experimental results about spring support structure and conventional support structure are showed in Table 1. P_1 is the initial load peak effected on the structure owning to chemical explosion; P_2 is the maximum pressure effected on the basis; P_1 and P_2 difference (in Δ P says) can be regarded as the dissipative external forces due to structural deformation and overall movement. ε_1, ε_2 refer to the maximum strain at the measuring point. W_1 is the displacement peak at the top of the arch structure (including the vertical deformation of the node and the overall vertical displacement of the structure); W_2 reflects the displacement peak at the bottom of the arch structure, namely the whole vertical displacement of the structure. Δ W is the vertical displacement at the top of the arch structure.

From Table 1, we can see that the strain value at the corresponding measuring point of the spring support structure are all smaller than that of conventional support structure and the average strain of the spring support structure is about 40% of the conventional support structure. In addition, we can see the bigger the whole displacement of the structure, the smaller the strain produced by the structure with the near dynamic loads.



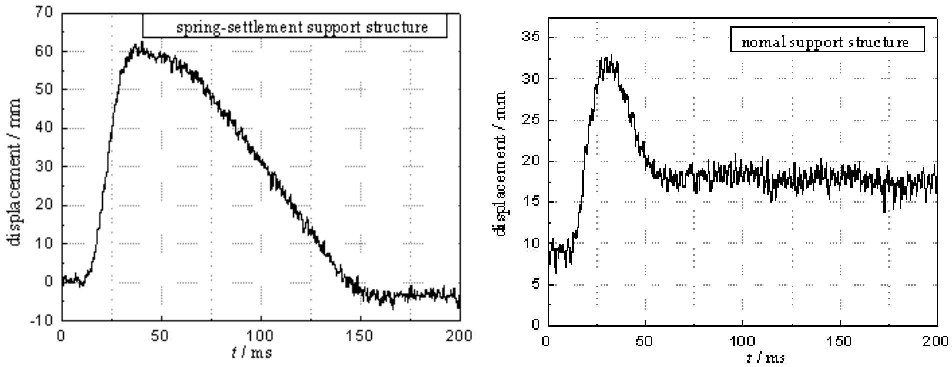
(a) Spring-settlement support structure (b) Normal support structure

Fig. 6: Pressure history curves of P1 point of spring-settlement support and normal support structure



(a) Spring-settlement support structure (b) Normal support structure

Fig. 7: Strain history curves of ε1 point of spring-settlement support and normal support structure



(a)Spring-settlement support structure (b) Normal support structure

Fig. 8: Displacement history curves of point of spring-settlement support and normal support structure

Table 1: Experimental data of different types of structures

Structure type	TNT/kg	Strain /ε		Structure type		Displacement /mm	
		ε_1	ε_2			W_1	W_2
Spring support structure	1	312	-200	0.07	0.04	13.3	13.0
	2	462	-410	0.10	0.07	25.0	24.0
	3	1500	-500	0.30	0.20	40.0	49.0
	5	2200	-930	0.58	0.54	63.0	64.0
Conventional support structure	1	929	-400	0.11	0.10	8.5	10.0
	2	1340	-800	0.16	0.20	11.0	8.0
	3	2700	-1340	0.40	0.40	14.0	11.0
	5	10000	-2600	2.00	1.10	24.0	5.0

Table 2: Value of $\Delta P/P_1$ of different types of structures

	Spring support structure				Conventional support structure			
TNT/kg	1	2	3	5	1	2	3	5
P_1/MPa	0.07	0.10	0.30	0.58	0.11	0.16	0.40	2.00
P_2/MPa	0.04	0.07	0.20	0.54	0.10	0.20	0.40	1.10
$\Delta P/P_1$	0.43	0.30	0.33	0.07	0.09	-0.25	0	0.45

Table 3: Value of ΔW of different types of structures

	Spring support structure				Conventional support structure			
TNT /kg	1	2	3	5	1	2	3	5
	13.3	25.0	40.0	63.0	8.5	11.0	14.0	24.0
W_1/mm	13.0	24.0	49.0	64.0	10.0	8.0	11.0	5.0
W_2/mm	0.3	1.0	-	-	-	3.0	3.0	19.0
ΔW								

In Table 2, $\Delta P/P_1$ is used to represent the energy consumption efficiency of the structure. The bigger its value, the more the energy acted by external force consumes. From Table 2, it is known that the energy dissipation efficiency of spring support structure significantly greater than conventional support structure. But when the charge weight is 5 kg, the energy dissipation efficiency of conventional support structure is partial big unusually and this may be caused by the plastic strain of the conventional support structure according to the Fig. 7b. For the spring support structure, the structure strain is general lesser and they don't produce the plastic strain in addition to 5 kg charge weight.

So we can believe that for spring support structure, its energy consumption is mainly caused by the subsidence of spring support. Its working principle is: when external load was applied and then spring was compressed and stored energy; when external load reduced and disappeared in the process, spring elongated and released energy, because of the influence of damping produced by the overlying soil, the energy was consumed gradually. But conventional support structure is mainly depending on structure's deformation to store energy and relies on large plastic deformation to consume energy. In addition, we can judge from the value P_2/P_1 $(1 - \Delta P/P_1)$ that the influence of spring support makes the pressure which the structure effect on the basis to reduce.

Compared to the conventional support structure, although the spring support structure has a greater whole displacement, but the local deformation of the structure is less, which is reflected in the experimental results showed in Table 3 of the value W2 bigger and value ΔW less. This conclusion can be derived by the strain results showed in Table 1.

THE ENERGY DISSIPATION MECHANISM OF THE EXPERIMENT STRUCTURE

Under the action of vertical load, the whole stiffness of the structure with the spring-settlement support mainly depended on the spring stiffness and little depended on the structure stiffness. Because the mass and stiffness of the experiment structure were small, the vibrated characteristic of experiment structure was negligible and its deformation is basically the same as the surrounding soil deformation. It was reasonable to use the "Arch effect" theory to analysis the energy dissipation mechanism of the experiment structure.

The theory is that the pressure that compression wave action on structure is relevant to the arch effect value A and puts forward the dynamic pressure formula action on the structure in calculating plane problem:

$$P_j = P_h(1 - A)$$

In which,

P_h = The incidence pressure on the structure
A = The arch effect value

By transposition, the above equation becomes:

$$A = 1 - \frac{P_j}{P_h}$$

When the compression wave propagates in the dust, the free field stress of the structural surroundings will be redistributed and the rule is: The stress transfers from the relatively flexible area to rigid area, which is called the "arch effect" phenomenon. With the size of the arch effect, we can calculation how much the top pressure of the structure as a percent of the free field pressure at the point. The greater the arch effect, the smaller the percent. Obviously, arch effect has close relation to structural characteristics, soil characteristics and so on. If the relatively compressibility of the structure is very high and the actual pressure of the roof will be very small and even equal to zero. If the stiffness of structure is much higher than soil's, then the pressure will be higher than the free field pressure.

Depending on the shear and compressive capacity of the soil, the stress in compression medium transfers to around the structure. So, the arch effect in essence is the use of shear capacity of soil to bear the compression stress. Therefore, it can be said that the arch effect is the function of shear strength of soil and structure deformation performance.

For shallow buried structure, the arch effect theory is that, the soil column above the structure will move with the structure in the dynamic loads and at the same time the shear stress τ produces in the soil column perimeter:

$$\tau = c + P_h k t g \phi$$

where, c, P_h, k and ø, respectively, denote the coefficient of soil viscosity, the free field pressure at corresponding position, the coefficient of soil lateral pressure and soil angle of internal friction.

Obviously, to make the maximum shear stress of the soil, the movement between soil column and its surrounding soils should achieve a certain amount of displacement and then the arch effect is the most obvious. The displacement is relevant to the soil properties and the width of structure.

CONCLUSION

Through the above analysis, we can draw the following conclusion:

- Under the action of explosion load, the energy dissipation efficiency of spring bearing structure significantly greater than conventional bearing structure, making that the pressure which the structure effect on the basis reduces. Its working principle is: when external load was applied and then spring was compressed and stored energy; when external load reduced and disappeared in the process, spring elongated and released energy, because of the influence of damping produced by the overlying soil, the energy was consumed gradually. But conventional support structure is mainly depending on structure's deformation to store energy and relies on large plastic deformation to consume energy.
- In the same dynamic loads, the strain from conventional bearing structure is greater than the spring support structure and the bigger the whole displacement of structure, the smaller the strain of the structure. The spring support can reduce the internal force and relative displacement amplitude of the structure, thus reduces the structural dynamic loading and improves the bearing capacity of the structure.
- In the same dynamic loads, the smaller the stiffness of spring support structure, the larger the structure displacement. But the spring stiffness should match with the designed load. If the spring stiffness is too small, then it may lead spring to achieve maximum deflection and out of action.

This experimental research is only the preliminary exploration of the influence of bearing capacity of the Shallow buried structure with the Spring-settlement support under blast action. Experimental data indicates that the spring support structure can significantly reduce the structural dynamic loading. But as a result of the experimental scale is limited and the data obtained is relatively less, so it is difficult to draw a *regular* conclusion.

We will further carry out the research about settlement mode and structural unloading mechanism and explore the relationship between the unloading effect and the factors such as structure stiffness, structure span, structure form, support settlement, load matching requirements, so as to put forward a practical settlement structure design calculation method for settlement structure to guide the engineering design and construction and also to improve the bearing capacity of the structure.

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