DEVELOPMENT OF LIFT-UP METHOD FOR REHABILITATION OF SETTLED PRESTRESSED CONCRETE PAVEMENTS

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A new lift-up method for prestressed concrete (PC) pavements has been developed as a rehabilitation method for adjusting the unevenness of pavements, when they have unacceptable settlement and differential settlement in particular. The procedure of the newly developed lift-up method is as follows. Installation fittings for jacks and reaction beds are provided only at the settled area of the pavements when lift-up work becomes necessary. Hydraulic jacks are attached to the installation fittings and the PC slabs are lifted up. The lift-up operation is conducted by automatic control of the jack stroke lengths and finally, the gap created between the PC slabs and the base courses is grouted. It is confirmed from the results of the lift-up tests in test pavements that PC slabs can be lifted up rapidly, precisely and safely by using this newly developed lift-up method.

Introduction

Recently, many airports in Japan are constructed on reclaimed land or high embankments. In such cases it is forecast that unacceptable amounts of settlement, especially differential settlement due to consolidation will occur after completion of construction and some maintenance or rehabilitation work will be necessary in service.

Existing counter measures for settled concrete pavements are a concrete overlay or reconstruction of the settled slabs. These existing methods are undesirable because a long curing time for concrete is necessary, requiring that the facilities be closed. Because of this, development of a new maintenance or rehabilitation method, in which settled concrete pavements can be easily rectified at night so that closure of the facilities is not necessary during the daytime, has been strongly desired.

The lift-up method of settled concrete pavements has been considered as an answer to this. For such lift-up work, a prestressed concrete (PC) pavement may be the only pavement type in consideration of the flexibility of the pavement and the thickness or weight of concrete slabs, as far as the capacity of jacks and the interval are concerned. Therefore, only PC pavements will form the object of this study.

There are two existing lift-up methods for PC pavements. One is to pull up the PC slabs by hydraulic jacks, adjust the level of the base courses and reset the PC slabs. The other is to attach screw jacks in the PC slabs and reaction plates on the base courses in advance, and lift up the settled portion of the PC pavement by turning screw jacks manually. The former is only applicable to narrow PC pavements. The latter is applicable to a wide and large PC pavement, but there are many problems such as over-capitalization for the lift-up equipment, long working hours and too much labour.

A newly developed lift-up method is slightly similar to the screw jack method. However, it is more general and economical than existing methods, because it is not necessary to install lift up equipment in the PC pavement in advance, and only requires that they be installed at only the settled portions of the PC pavement. Also, the speed and the reduction of labour have been attained by this new method through mechanization and application of automatic system.

Existing Lift-up Methods

Outline of Existing Methods

Though some kinds of lift-up methods for PC pavement slabs were developed and tried in the past, the following methods have only been used in practice.

(1) Pull-up Method

This method can only be applied to a PC slab of narrow width.

In this method, a PC slab is pulled up by hydraulic jacks fitted to steel girders crossing the PC slab as shown in Figure 1. Steel tension bars for pulling up the PC slab are installed on the top or side of the PC slab.

This method was adopted for lifting up gantry crane paths in container handling yards that were constructed on the reclaimed land.

(2) Screw Jack Method

This method was developed for wider and larger PC slabs.

In this method, steel reaction plates and attachments for screw jacks are laid beforehand on the base course or in the PC slab in the area in

which settlement will be expected.

When settlement of the PC slab occurs, screw jacks are attached at lifting points and the settled PC slab is lifted up by turning the jacks manually.

This method was adopted for half of the PC pavement slab in the hangar at Iwakuni Air Force Base, because the half area was reclaimed and expected to settle. The PC slab in this area was lifted up twice, with the progress of settlement. Figure 2 shows the schematic illustration of this example.

Another application of this method was at New Aomori Airport. The apron area of about 20,000 m^2 in this airport was constructed on a high embankment. This high embankment area was therefore expected to settle, and so lift-up equipment was installed in the PC pavement at the construction time.

Figure 1. Pull-up method.

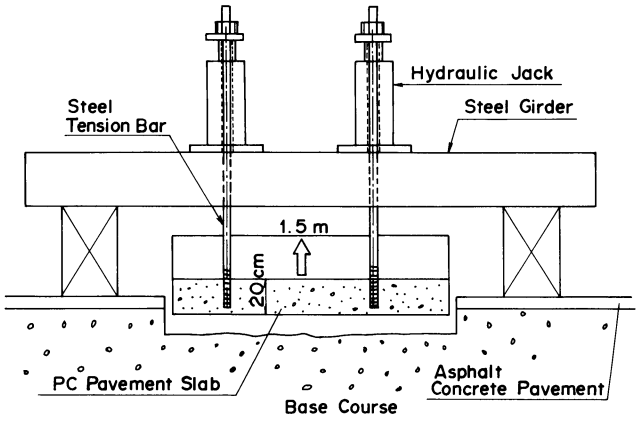
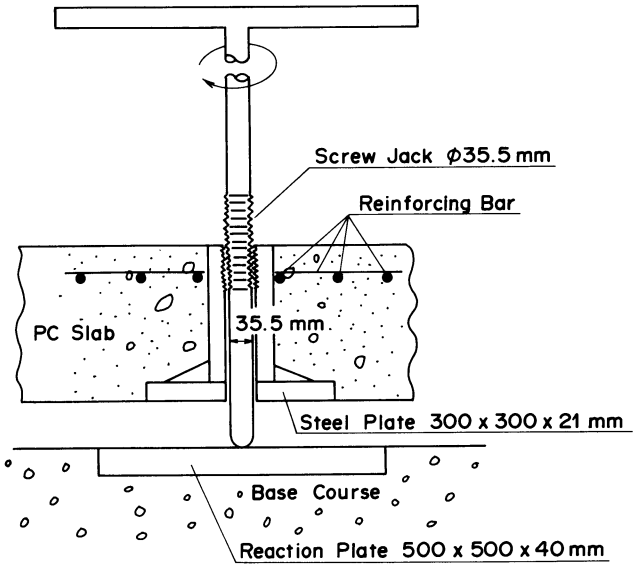


Figure 2. Screw jack method.



Problems of Existing Methods

The application of the pull-up method is limited to narrow PC pavements.

On the other hand, the screw jack method is applicable to wide and large pavements. However, there are the following problems in this method.

(1) Lift-up equipment is installed at construction time, so this method can not be applied in the area where settlement is not expected beforehand. Therefore, unless settlement is expected in a restricted area, the lift-up equipment should be installed in a wider or the whole area. Construction cost therefore becomes higher.

(2) This method is not effective in reducing the labor cost because two workers are required to turn the jacks at each lift-up point.

(3) When the amount of labor is restricted, it is difficult to lift up a wide and large pavement slab in the short term, because the slab must be lifted up partially and little by little.

(4) Because lift-up work in this method is conducted manually, it is difficult to closely control the lift-up work at each point or all points to stop PC slab damage such as cracking during lift-up operation.

Fundamental Concept of New Lift-up Method

A new lift-up method for PC pavement slabs has been investigated through referring a screw-jack method and solving the problems involved in it. As a result, the new lift-up method whose procedures are shown in Figure 3 has been developed.

First, ϕ 150 mm holes are cut in PC slabs with a core boring machine. Base course materials are excavated through the holes with a special boring machine and reaction concrete beds are made there. After the concrete is hardened, installation fittings for jacks are attached to the holes and jacks are fixed to the installation fittings.

The PC slabs are lifted up by the reaction force of the jacks from the reaction beds.

The operation can be carried out quickly, precisely and safely through checking the pressure of the jacks and the lift-up heights by an automatic control system. The lift-up heights are displayed on a computer and plotted on the paper in real-time at any stage from the start to the end of the operation. This system gives us the information of the lift-up work in a moment and facilitates execution control of lift-up work over wide areas.

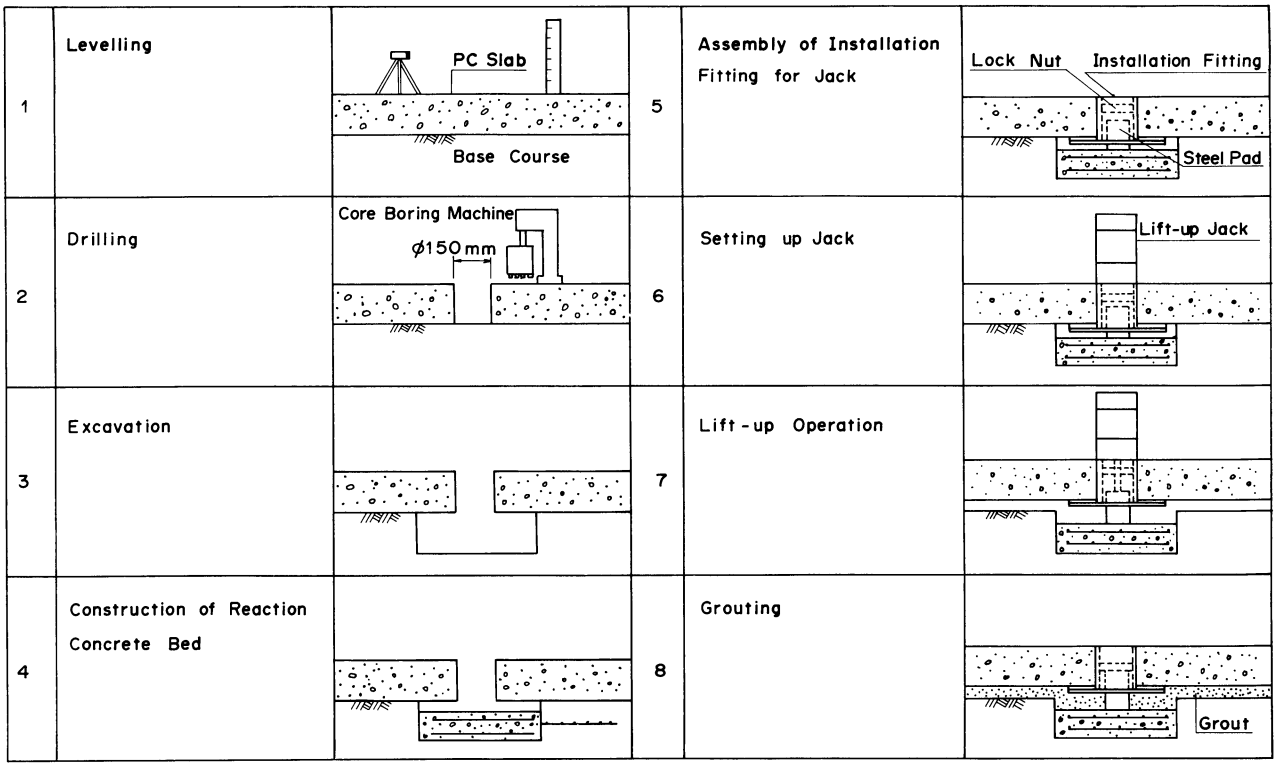
The gap between PC slabs and base courses is grouted after the lift-up work.

Development of Equipment for New Lift-up Method

The main purposes of the new lift-up method are to improve the safety of the PC slabs during lift-up work, to speed up the lift-up work and to reduce the cost of construction including labor.

The following equipment and execution method for lift-up work have been found to satisfy the purposes.

Figure 3. Procedures in new lift-up method.



Hydraulic Jack for Lift-up Work

To lift up PC slabs safely and speedily requires a strictly controlled lift-up work at all lift-up points. This requirement made the adoption of an automatic control system inevitable. The consideration led to the use of electrical, hydraulic jacks, the capacity of which was designed to 294 kN and the stroke to 150 mm, in consideration of the PC slab thickness, the maximum distance between jack points, and the maximum planned lift-up height.

In the case of lifting up wide and large PC slabs, it is impossible from the point of view of economy to equip jacks all over the area and to lift up the area simultaneously. Therefore, the slab must be lifted up by a limited number of jacks, and then the jacks are moved from the points to the next assigned points.

Considering the above-mentioned lifting sequence, the jack was contrived so as to be easily installed to and removed from PC slabs. The jack is also equipped with a sensor which measures the jack stroke length and transmits the data to the control apparatus.

Installation Fitting for Jack

The lift-up load of a jack has to be spread over a wide area so as not to harm the PC slab concrete. If the load is not well distributed, harmful phenomena such as cracking will occur in the slab which is not reinforced with steel bars as the like.

Figure 4 shows the results of lift-up tests using a steel pipe as an installation fitting for a jack. As recognized from Figure 4, the PC slab was cracked at lift-up load of 98 kN and failed at lift-up load of 147 kN due to punching shear. These results show that only steel pipe is not suitable as the installation fitting because the slab cannot bear the lift-up load which is estimated to be applied in practice.

On the basis of this result, an installation fitting with a steel pipe and a circular steel plate was contrived for more effective device.

Figure 5 shows this installation fitting. This fitting supports the bottom of a PC slab and distributes the lift-up load to wider area than the before-mentioned pipe method.

It was presumed that the larger diameter of the plate, the more effective the spread of the lift-up load, but the diameter was designed to be 45 cm in consideration the relationship between the maximum tangential stress around the hole in the PC slab and the diameter of the circular plate, as shown in Figure 6, which was obtained from finite element analysis.

The circular plate is divided into three pieces that are smaller than the hole in the PC slab. These pieces are reassembled in the space under the slab by welding.

After completion of the first lift-up work, the PC slab is held by lock nuts and the jacks are taken off from the installation fittings and moved to the next points. Therefore, some hooks are made in the installation fitting.

Figure 4. Pull-out test results for steel pipe as installation fitting.

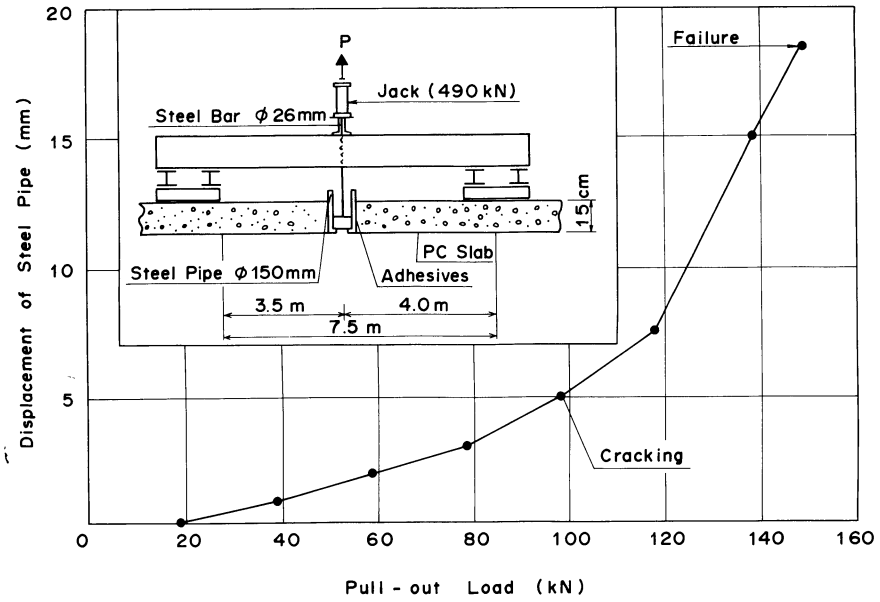


Figure 5. Equipment for lift-up method.

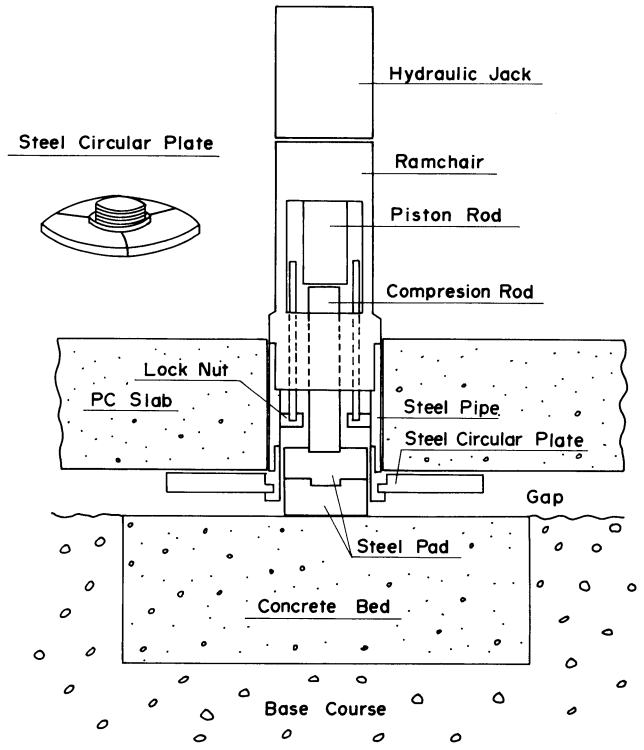
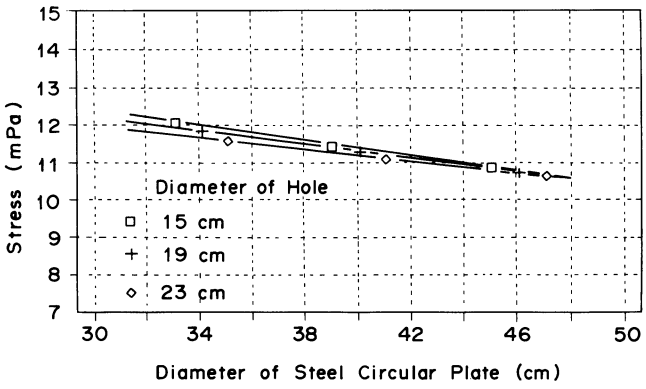


Figure 6. Maximum tangential horizontal stress around hole (Lift-up load:196 kN).



Reaction Bed

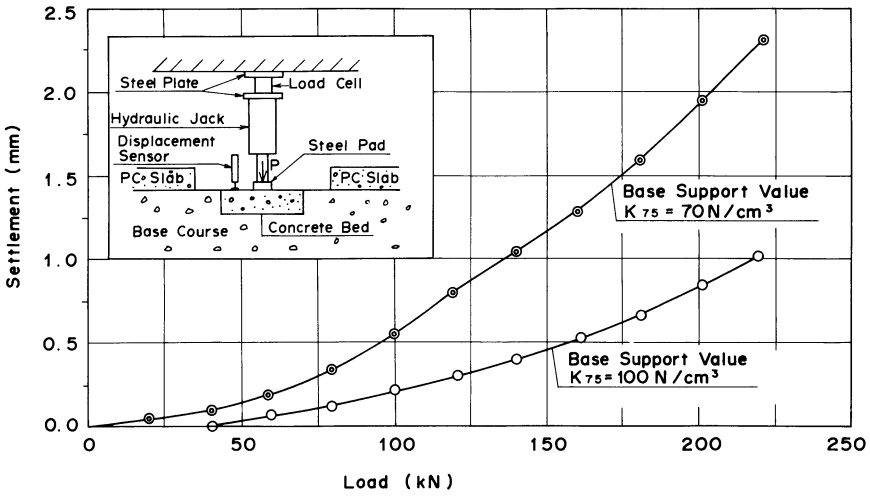
The lift-up load of a jack acts on a reaction bed, which distributes the load over the base course so that the settlement on the base course remains small.

The reaction beds are concrete beds with a diameter of 45 cm and thin steel pads about 15 cm in diameter.

The settlement of the reaction bed during loading is related to the bearing capacity of the base course, and the relationship between the lift-up load and settlement, as shown in Figure 7, was obtained from the preliminary test.

Each jack is operated in accordance with the predetermined stroke length. This stroke length can be calculated from the planned lift-up height and the settlement of the reaction bed obtained from the relationship like Figure 7.

Figure 7. Relationship between load and settlement of reaction bed.



The concrete bed is made as follows; A hole is excavated in the base course using a drilling machine which was designed for this exclusive use. Concrete is placed into this hole. When lifting PC slabs, a few steel pads are piled up to a height of about 10 cm on the concrete bed. The lift-up load of a jack is transmitted from steel pads to a concrete bed.

This steel pad was devised in order to fix lift-up slabs. They can be held by fixing the steel pads on the installation fittings with lock-nuts. Also, lift-up operation can be conducted again in the future, by piling up new steel pads on the existing ones which remain after grouting into the gap between the lifted-up slab and the base course.

Control System for Lift-up Operation

Lift-up work is conducted by controlling jack stroke length detected with a sensor in the jack and transmitted to the control apparatus.

The control apparatus which has a control circuit for each jack can switch the hydraulic circuits for each jack on and off in real-time, comparing the predetermined stroke length with the actual stroke length which is transmitted continuously from each jack.

In order to strictly maintain safety of the PC slabs during the lift-up work, the control apparatus adjusts the stroke speed of each jack which corresponds with the predetermined stroke length. Control is conducted for fractions of the predetermined stroke length.

Owing to the above control method, the stroke lengths of all jacks can reach the first steps almost simultaneously and such lift-up work is automatically continued until the final step.

Once the load of any jack reaches the bearing capacity of the PC slab, the hydraulic pump will be stopped, and all lift-up work will be suspended.

Data such as the jack stroke length and lift-up load of each jack are processed with a computer, and displayed on a CRT, and drawn on paper by a plotting machine in real-time.

Owing to the control system and processing system, lift-up work has become intrinsically safe and efficient.

Grouting Method

After completion of the lift-up work, some material such as cement milk or mortar will be filled into the gap between the PC slabs and base courses.

The cost of grouting material will amount to large percentage of the total cost in the case of lifting up a wide and large PC slab. Development of an economical grouting method including its material is very important in order to bring the lift-up method into practical use.

In the special situation where rapid execution is necessary, a grouting method using rapid hardening cement as shown in Figure 8 can be used, even though it is very expensive.

Figure 8. Grouting method using rapid hardening cement.

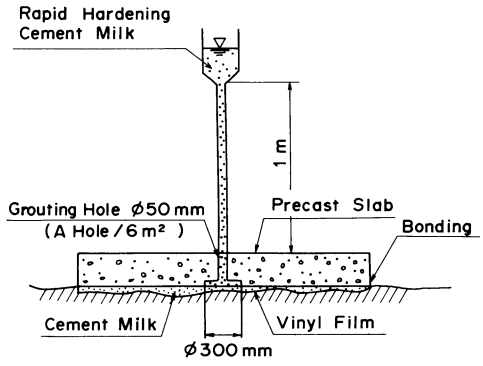
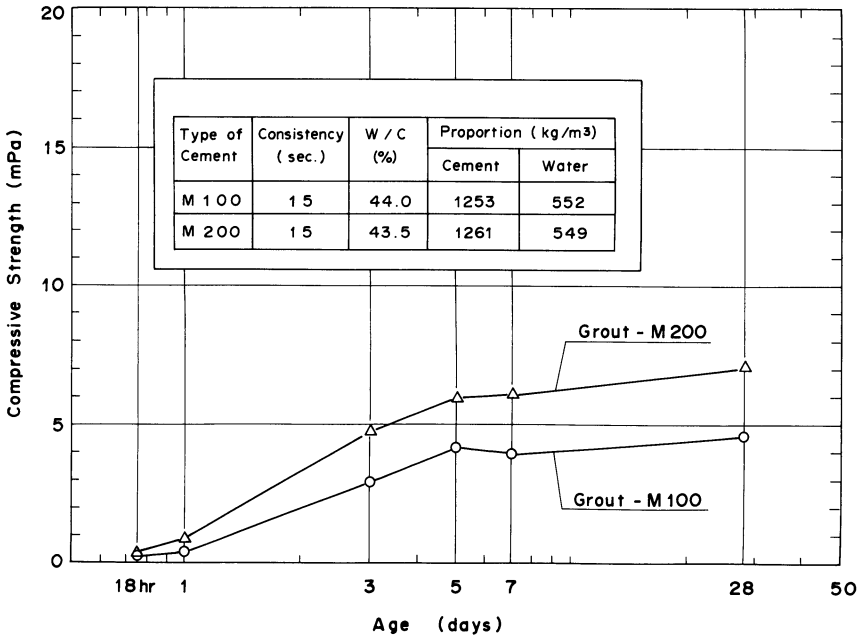


Figure 9. Relationship between compressive strength and age for cement grout.



In the case where rapid execution is not required, a grouting method using economical cement had better to be developed in order to reduce the grouting cost. At the age of one or two days, developed grouting material attains sufficient strength to carry the traffic load on the PC slab as shown in Figure 9.

The above two kinds of grouting methods, however, do not satisfy the conditions of economy and rapid performance in execution. A blowing method using dry mixture of sand and cement, therefore, is now being studied in order to satisfy these requirements. Grouting tests are conducted using a transparent slab, of which size is 6 m x 6 m, in order to examine the degree of grouting into the gap.

Lift-up Tests of PC Slab in Test Pavement

Lift-up tests of a PC slab were conducted for the test pavement shown in Figure 10. The base support values of the test pavement are 30, 70 and 100 N/cm and the effective amount of prestressing introduced in the PC slab is about 2450 kPa.

As the settlement of the reaction beds at the section of base support value of 30 N/cm^3 was very large during loading, lift-up jacks were installed at the nine points shown in Figure 11, except in the section of base support value of 30 N/cm^3.

The interval of the jacks was determined at about 5 m on the basis of the test results at Iwakuni Air Force Base. According to the before-mentioned procedure and using the newly developed equipment and material, the following three kinds of lift-up tests were conducted.

① Slope type lift-up test (1)
② Slope type lift-up test (2)
③ Maximum displacement test between jacks

Slope Type Lift-up Test (1)

The planned lift-up height at each jack point was determined as shown in Figure 12 in order that maximum lift-up height at the jack points of P1 to P3 be 30 mm and the shape of the PC slab be a straight line slope.

As the settlement of each jack was 1.0 to 2.0 mm for the predicted load of 98 to 196 kN of each jack during lift-up operation, the predetermined jack stroke length of each jack was decided as the sum of the planned lift-up height and 2.0 mm.

The speed of each jack was set to correspond to the jack stroke length. The lift-up operation was controlled by comparing the actual stroke length with the predetermined stroke length of each jack at the trisected steps of the jack stroke lengths. Figure 13 shows the lift-up condition during the operation.

Table 1 shows the actual lift-up heights of the jack points which were measured by levelling after the lift-up work was finished. As the measured lift-up heights approximately correspond to the planned lift-up heights, it is recognized that the predicted lift-up work was conducted satisfactorily.

Table 2 is a comparison between the measured lift-up load and the theoretical lift-up load calculated by finite element analysis. Both are in good agreement. The reason why there is a little difference at the points of P1 to P3 is for lack of considering the thickened end of the slab in the theoretical analysis. From this result, we can predict the details of lift-up work from finite element analysis.

Slope Type Lift-up Test (2)

The planned lift-up heights were determined as shown in Figure 14 in order that the stroke length

Figure 10. Test pavement.

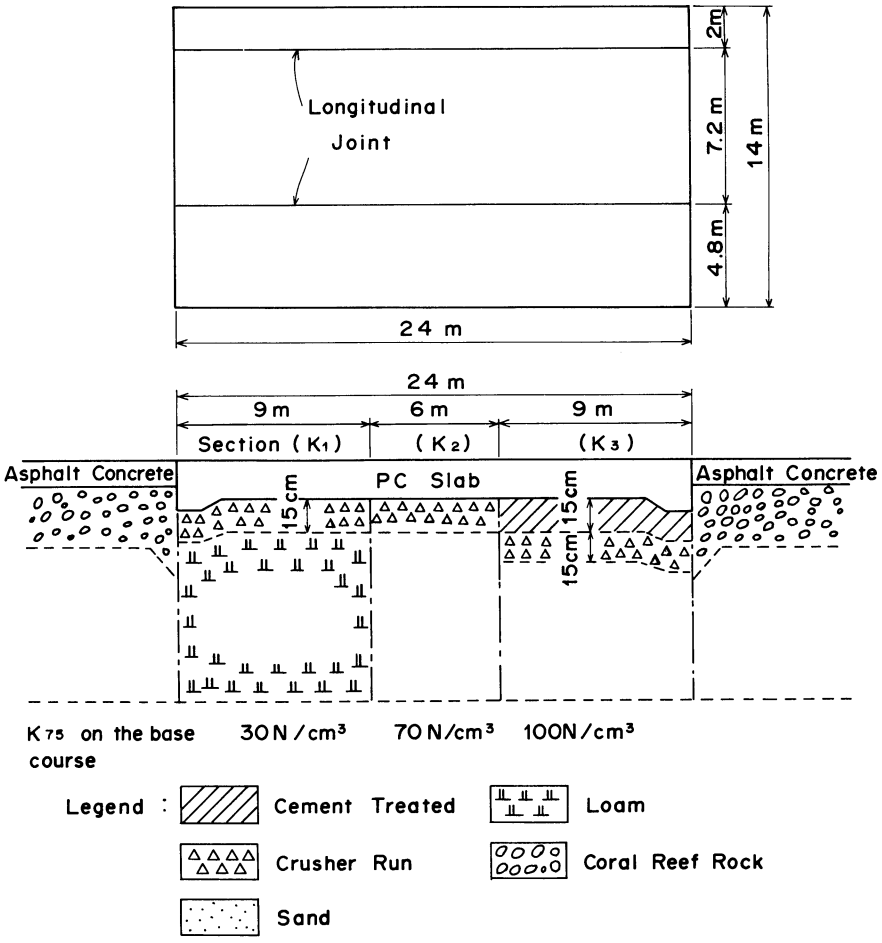


Figure 11. Jack points.

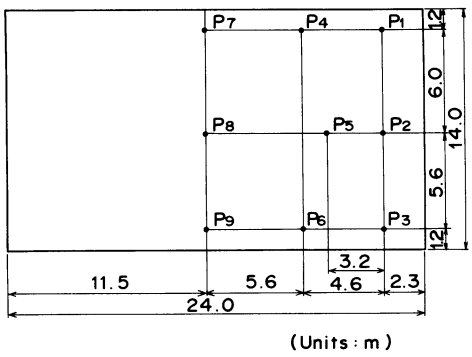


Figure 12. Planned lift-up heights for slope type lift-up test (1).

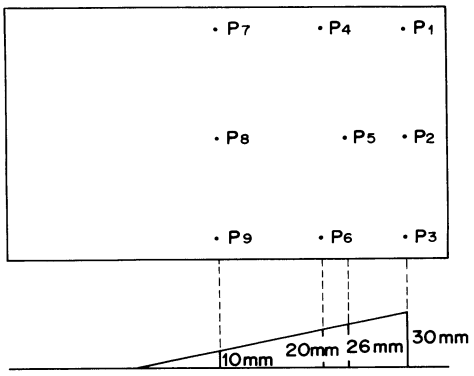


Table 1. Comparison between planned lift-up height and measured lift-up height.

Point	P1	P2	P3	P4	P5	P6	P7	P8	P9
Planned lift-up height	30	30	30	20	26	20	10	10	10
Predetermined jack stroke length	32	32	32	22	28	22	12	12	12
Measured lift-up height	30	29	28	22	27	22	10	8	9

(Units:mm)

Table 2. Comparison between measured lift-up load and theoretical lift-up load.

Point	P1	P2	P3	P4	P5	P6	P7	P8	P9
Measured lift-up load	99	167	97	73	141	66	105	172	120
Theoretical lift-up load	85	91	74	70	188	77	119	162	104

(Units:kN)

Figure 13. Example of lift-up condition during lift-up operation.

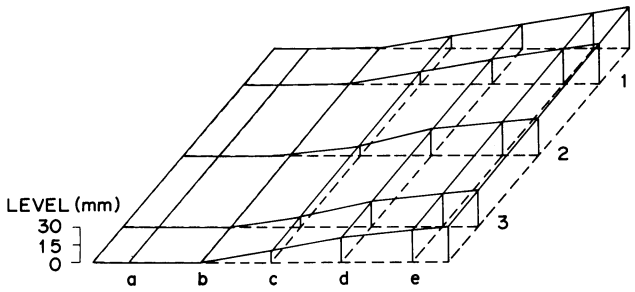
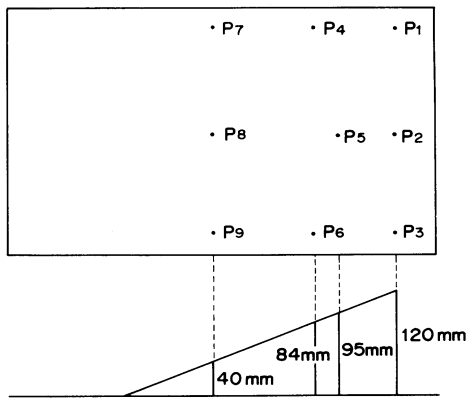


Figure 14. Planned lift-up heights for slope type lift-up test (2).



of the jacks of P1 to P3 be maximum and the shape of the PC slab be a straight line slope.

The predetermined jack stroke length of each jack was decided as the sum of the planned lift-up height and 2.0 mm, for the same reasons as mentioned in the slope type lift-up test (1).

Lift-up operation in this test was conducted in the similar manner as in the slope type lift-up test (1), except for dividing the stroke lengths into ten parts for the control stages.

Table 3 is a comparison between the actual lift-up height, which was measured after the lift-up work was finished, and the planned lift-up height. It is also confirmed from this result that the predicted lift-up work was conducted satisfactorily. Figure 15 shows the PC pavement lifted up to the planned lift-up heights.

Table 4 is a comparison between the measured lift-up load and the theoretical lift-up load calculated by finite element analysis. Both also are in good agreement in this test.

Maximum Displacement Test between Jacks

This test is to measure the displacement between adjacent jacks until cracking occurs on the surface of the PC slab. The PC slab was deformed by jacks as in the shape shown in Figure 16. At first, all jack points were lifted up at the same height of 10 mm and the points of P1 to P6 were gradually lifted up while the height of the points of P7 to P9 were kept to be 10 mm.

During this type of lift-up test, cracks occurred along the line by drawing the jack points of P4, P5 and P6 at the displacement shown in Table 5.

General Applicability of Newly Developed Lift-up Method

It was confirmed from the above-mentioned test results that settled PC slabs can be fundamentally

Table 3. Comparison between planned lift-up height and measured lift-up height.

Point	P1	P2	P3	P4	P5	P6	P7	P8	P9
Planned lift-up height	120	120	120	84	95	84	40	40	40
Predetermined jack stroke length	122	122	122	86	97	86	42	42	42
Measured lift-up height	120	118	119	86	94	86	39	36	36

(Units:mm)

Table 4. Comparison between measured lift-up load and theoretical lift-up load.

Point	P1	P2	P3	P4	P5	P6	P7	P8	P9
Measured lift-up load	113	204	89	72	119	75	124	224	130
Theoretical lift-up load	73	121	76	87	129	95	127	198	131

(Units:kN)

Figure 15. Lifted-up PC slab.

Figure 16. Maximum displacement test.

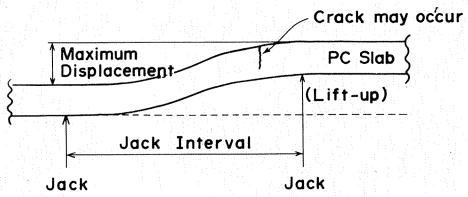


Table 5. Displacement between jacks at the cracking on the surface of PC slab.

Section	Displacement
P4~P7	45.3
P5~P8	36.3
P6~P9	45.1

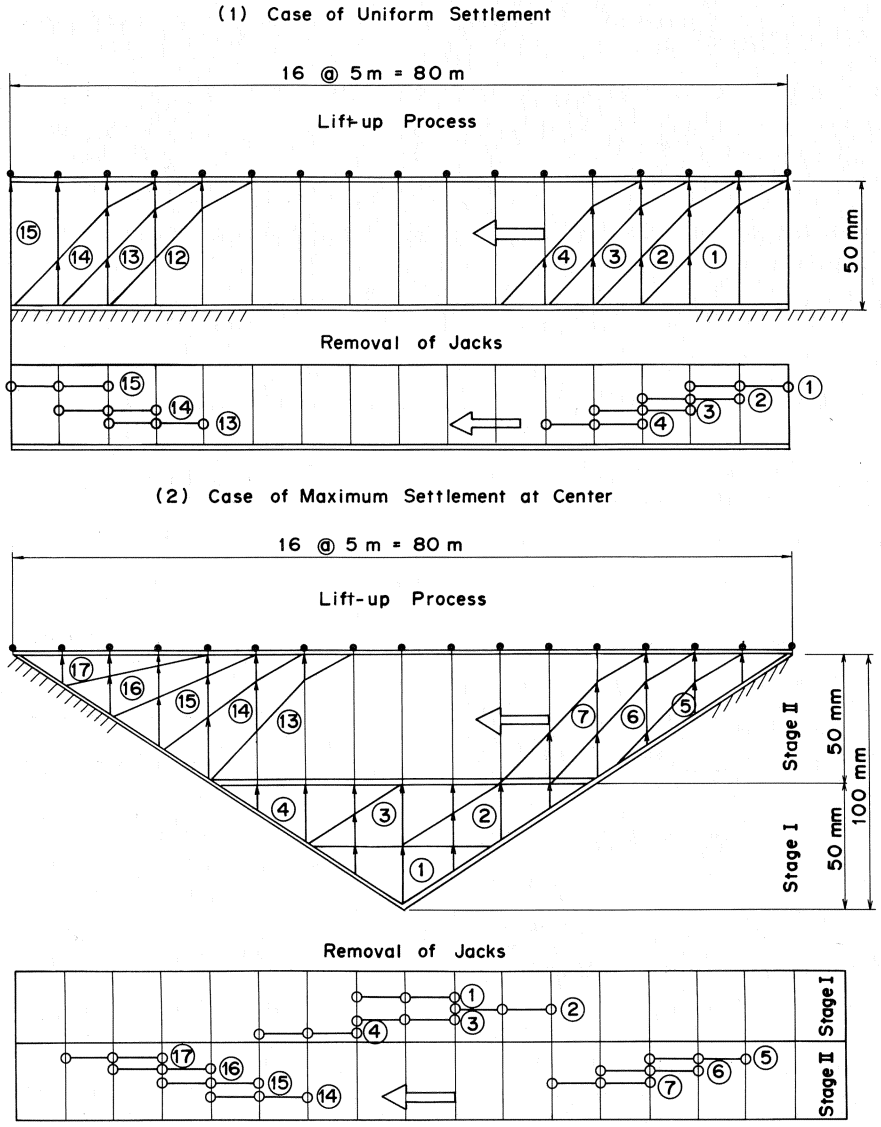
(Units:mm)

lifted up by the newly developed method. However, as there are PC pavements different from the test PC pavement, and the other settlement types of PC pavements different from the tested straight slope type, it is necessary to investigate how to lift up for these conditions as well. When the settled area of the PC pavement is small, jacks are installed all over the area and the area is simultaneously lifted up. However, when the settled area is large, the area cannot simultaneously be lifted up owing to the limited number of jacks. In the case of the lift-up work for the large settled area of PC pavements, it is necessary to shift the jacks. After the lifted-up area is temporarily held with lock nuts, the jacks are taken off and moved to the next area and the lift-up work continued. The entire settled area is lifted up by repeating this.

Figure 17 shows typical settlement types of PC slabs and lift-up procedures for them. It may be easy to lift up PC slabs having other settlement types through applications and modifications of the lift-up patterns as shown in Figure 17.

An appropriate jack interval should be decided for rational lift-up work and for keeping the PC slabs free from damage such as cracking. It may depend upon the strength of the jack point and the thickness of a PC slab. According to the results of

Figure 17. Lift-up process for typical settlement types of PC slabs.



the preliminary tests, the strength of the jack point is sufficient to lift up normal PC slabs, even though it is difficult to determine the strength quantitatively. Then, jack intervals were investigated in relation to the thickness of the PC slab.

Figure 18 shows the deformation and bending moment of a PC slab whose thickness is 18 cm and size is 30 m x 20 m, when the PC slab is lifted up at the center from the bottom. The deformation of the PC slab is zero at about 5 m from the jack in all the cases of jack strokes of 5, 10 and 15 mm.

Next, the deformation and bending moment of a section shown in Figure 19 were investigated when jacks are set at intervals of 5 m along the section and the PC slab is lifted up. From the result as shown in Figure 20, the section is uniformly lifted up.

Judging from the results shown in Figure 18 and Figure 20, a jack interval of 5 m may be optimum for PC slabs whose thickness is 18 cm. A similar analysis has been conducted for PC slabs having other thicknesses. Figure 21 shows the relationship between the PC slab thickness and an optimum jack interval. This may be referred to for planning and designing the lift-up work of settled PC pavements.

Concluding Remarks

A new lift-up method for PC pavements has been developed as a method for the maintenance or rehabilitation for adjusting the unevenness of the pavements, when they have unacceptable settlement, and differential settlement in particular.

Figure 18. Deformation and bending moment of PC slab during lift-up (Slab thickness: 18 cm).

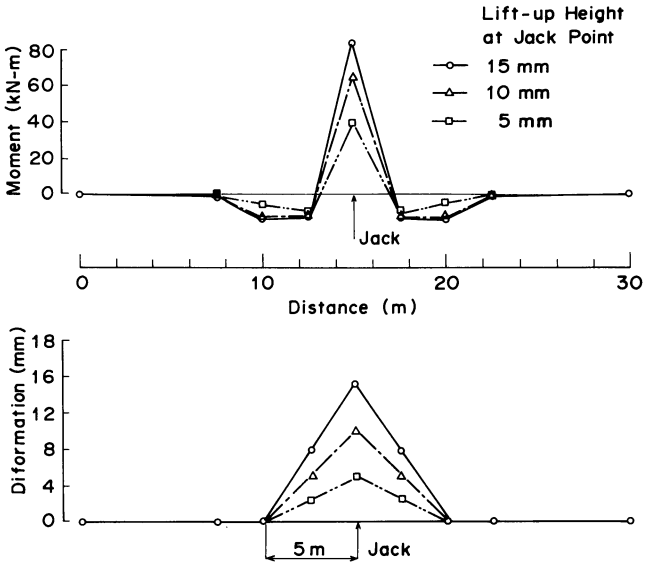


Figure 19. Examined section of PC slab.

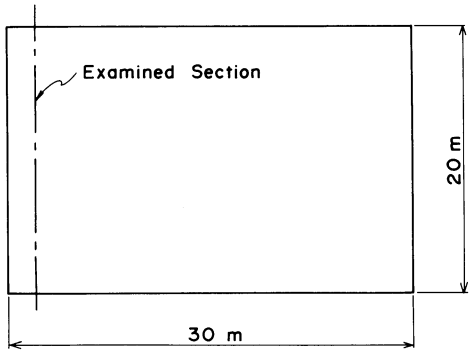


Figure 20. Deformation and bending moment of examined section of PC slab during lift-up (Slab thickness:18 cm).

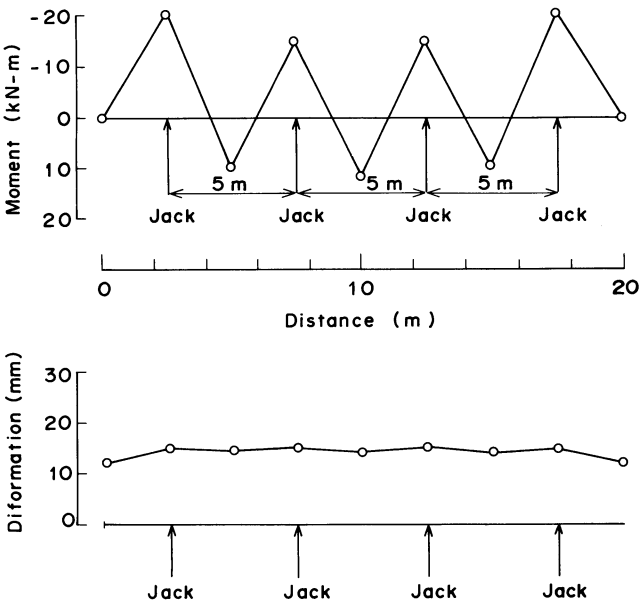
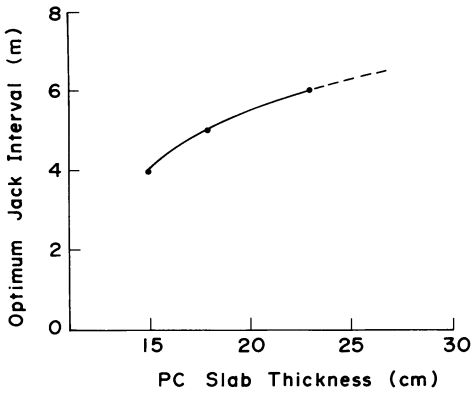


Figure 21. Relationship between PC slab thickness and optimum jack interval.



In the new lift-up method, installation fittings for jacks and reaction beds are provided only at the settled area of PC pavements when lift-up work is necessary. Hydraulic jacks for the lift-up work are attached to the installation fittings and PC slabs are lifted up. The lift-up operation is rapidly conducted through the automatic control of jack stroke lengths in keeping the safety of PC slabs. The gap between PC slabs and base courses which is created from the lift-up work is grouted with newly developed cement milk.

It was found from the results of the lift-up tests in the test pavement that PC slabs can be lifted up rapidly, precisely and safely by this newly developed lift-up method. As the performance of the lift-up work corresponds well with the results of finite element analysis, we may be able to predict the performance of the lift-up work for other pavements by using of the finite element analysis and conduct its work safely and effectively.

The newly developed lift-up method is more popular and economical than the conventional methods. Faster work and the reduction of labour can also be attained in this new method. It can be expected to find wide practical use in the future.