A Study of Cardboard Voids For Prestressed Concrete Box Slabs *

by **George J. Ziverts****

SYNOPSIS

This paper is one of the first published on this subject in the concrete industry. Its purpose is to rid the precast concrete industry of the problems arising from void failures and provide theoretical as well as practical data, theory and technology in the art of making voided concrete products.

The paper consists of four parts. The first part describes the reasons for void problems and manufacturer's relation to inspectors and inspection procedures. By showing weight tables of some 358 box slabs, the writer presents industry's problem with facts and figures, and further establishes diagrams of void deformations and overweight percentages which are discussed in detail in the balance of the report.

Part II deals with the technology of voids and provides technical as well as practical suggestions and recommendations. It also provides theory and practical guidance for void users, and clarifies the problem of waterproofing and moistureproofing—actually the most important items in void making and using. A special section has been devoted to the problem of holding the void in position, presenting methods of void hold-downs and a new approach for permanent void hold-downs. Void tolerances are discussed and developing of void specifications and standards is suggested.

Part III, which describes void testing, stresses the importance of full-scale void tests and proposes a specific void testing procedure that could be applicable to all manufacturers. In addition to the proposed procedure, this section also contains a proposed test setup, including necessary report forms and documents.

Part IV presents the conclusions and recommendations for the prestressed concrete industry.

**Editors Note: This article is continued from the June, 1964 issue of the Journal of the Prestressed Concrete Institute.*

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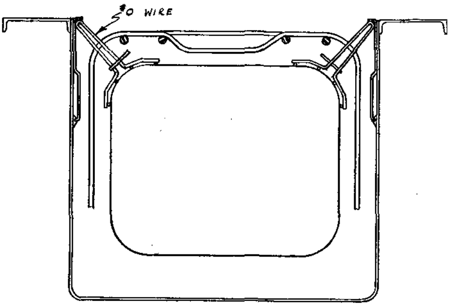


Fig. 34

A comparison of the direct and indirect hold-down method makes it obvious that the indirect system does the job. Indirect hold-downs provide continuous support against upward forces and secure the void against rotation and lateral movement. Side movement of the void is prevented by the use of two long prongs or side spacers with this system. It is suggested that all plants give careful study to the indirect hold-down method.

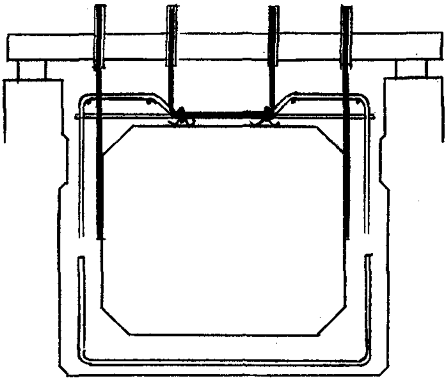


Fig. 35

The writer has designed and experimented with so-called "permanent" hold-downs (Fig. 34). Taking advantage of a little 1″ return on the shear key, a permanent hold-down made of #0 wire was fitted between the top of the shear key and upper corner of the void. The hold-downs were placed in pairs—one on each side of the void at a distance of 3′ between pairs of hold-downs. Hardboard shell void with wood frame was used for this test. The void behaved perfectly. It did not move at all in any direction.

The same test should be repeated by using corrugated cardboard voids in order to fully evaluate this type of hold-down.

Another system for a "permanent" hold-down is shown in Fig. 35. This system calls for reversing the principle of the so-called prong type hold-down: normally, the prongs, which are made of ¾ in. rebars, are welded to the hold-down beam running on top across the form. The new system calls for welding 1 in. I.D. metal pipe with the closed end at the top, which receives the prong that is attached to the reinforcing cage. This is exactly the same well-known system of hold-down—only reversed. Two other alternate systems are shown in Fig. 36 and 37.

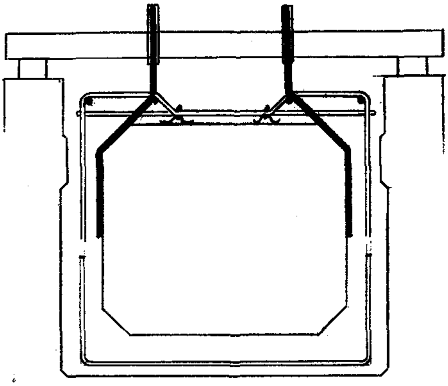


Fig. 36

Under this system the hold-down beams can be removed one hour, ten hours, twenty hours, or generally at anytime after the concrete has hardened, with no effect to void floatation or rotation. In the case of non-composite bridge deck, the protruding rebars can be cut off or burned off; but in case of composite bridge deck, these rebars can be bent and utilized as additional reinforcement for composite action.

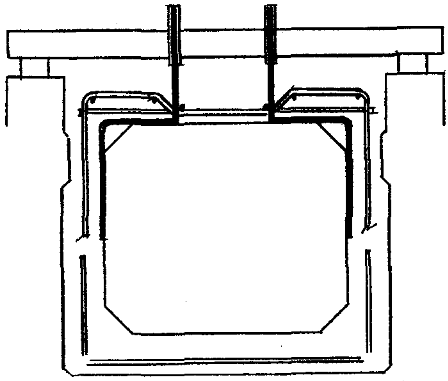


Fig. 37

DEFECTIVE VOID HOLD-DOWNS

Void hold-downs should be placed on the superintendent's equipment checklist and be inspected regularly. You will find in your own yard that a certain percentage of hold-downs are twisted, bent, broken or otherwise abused. Such hold-downs should be removed from the production line immediately and repaired or replaced.

Despite the fact that they are made of fairly heavy structural elements, void hold-downs get out of shape for several reasons: first, by misuse and mishandling; and, second, underdesigned hold-downs deflect under uplift forces.

In order to eliminate the above problems, three things have to be done:

1. Superintendents and foremen have to instruct their men to handle hold-downs with care.
2. Check hold-downs regularly during production. Also check whether the hold-downs provide required concrete coverage over the voids.
3. Design hold-downs properly. Let the engineers, not the superintendents or foremen, do this work.

PLACING CONCRETE

After the voids are properly placed, adjusted and secured in their final position by means of hold-downs, the crew proceeds with placing the concrete. There are two schools of thought on how concrete should be placed over the voids. One idea is that concrete should be placed directly in the webs, and the other thought is that concrete should be poured on top of the voids first and then distributed by means of vibration and raking.

In the first case (picture #38), the concrete is placed directly in the webs, and placing of concrete on top of the voids is done only when the webs are filled and fully vibrated. The advantage of this method is that it provides "clean" placing of concrete and the behavior of the void can be observed at all times until it is completely covered.

In the other case (picture #39) concrete is first placed on top of the void and then, with the help of rakes, shovels, and vibrators, evenly distributed over the voids and into the webs.

In both cases, leveling, screeding and finishing of the concrete is done in the usual manner. With void hold-downs still in place, all the forces

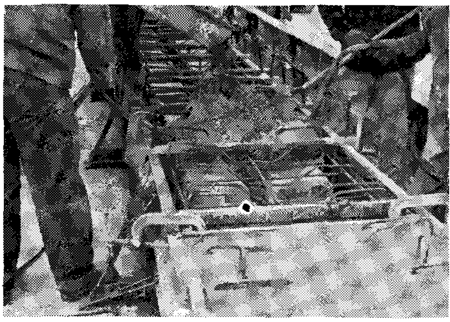


Fig. 38

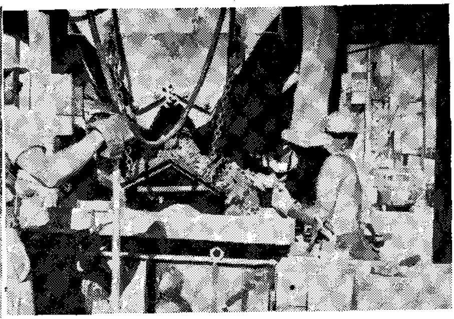


Fig. 39

are in equilibrium. By removing the hold-downs, the equilibrium is disturbed and, under normal conditions, the void tends to float, or rise, until these forces equalize. How high do the voids rise after removal of hold-downs? Several tests show that the voids rise approximately 3/16″ to 1/4″ in most cases for 42″ and 48″ sections, and around 1/8″ for shallower slabs. This is a factor which cannot be disregarded.

Under concrete pressure, the void usually tends to deflect upwards between two hold-downs. The greater the distance between hold-downs, the larger are deflections which can be expcted. The deflection of the void between hold-downs depends on many factors. The main ones are void rigidity and distance between hold-downs. Tests have shown that the deflection can easily reach 2″ and even 2½″ if the hold-downs are spaced at 5 ft., and 1″ up to 1½″ if the hold-down spacing is 3 ft.

Including 1/4″ floatation after releasing the hold-downs, the total combined void displacement figure can be disastrous. The table below shows the top depth thickness measurements of 42″ and 33″ box slabs as a result of void floatation. The required deck thickness was supposed to be 5″. The results were obtained through drilling of cores in two or three different locations in each void.

After the concrete has been placed, the problems are still not over. After removing the hold-downs, a certain portion of concrete is also removed, leaving fair sized cavities in the deck. These cavities are filled in by hand and the concrete is tamped or vibrated. Tamping and/or vibrating can further disturb the equilibrium and the void can rise again. It is particularly dangerous to hit the cage with the vibrator because the vibration is transmitted to the entire cage and the void.

Summarizing all the experience, opinions and test results, the following procedure can be recommended:

1. Provide hold-downs with 1/4″ deeper legs or plates—in other words, set the voids 1/4″ lower. After releasing the hold-downs, it is expected that the void will rise at least 1/4″, and the desired thickness of deck will thus be obtained (or very close to it).
2. a) Provide three hold-downs per 5 ft.-long void section if voids are not joined together by means of sleeves and stapling.
   b) If shorter voids are joined together to form a longer section, place

TABLE 1

DECK THICKNESS OF BOX BEAMS ON TWO PROJECTS (All Beams Rejected)

Project X–42″ BOX BEAMS

Required Deck Thickness	Actual Deck Thickness E. Void	C. Void	W. Void
5″	4½	4	4¼
5″	3¾	2⅞	3
5″	4¼	4⅝	3⅝
5″	3½	4⅛	3⅜
5″	4½	4⅛	4
5″	4¼	4¼	4½
5″	4¾	4¼	4¾
5″	3¾	3½	4⅝
5″	3¾	3¼	3½
5″	4½	4¼	5
5″	4½	4½	4⅞
5″	4½	4⅛	4½
5″	4¼	4	4
5″	4¾	4¼	4⅜
5″	3¾	3¾	4⅛
5″	4¼	4	4½
5″	4½	3¾	3½
5″	5	5	4¾
5″	4⅛	4½	4½
5″	5⅛	3¾	3¾

Project Y–33″ BOX BEAMS

Required Deck Thickness	Actual Deck Thickness E. Void	C. Void	W. Void
5″	4½		4
5″	4		3¾
5″	4		4½
5″	4¼		3¾
5″	4¼		4¼
5″	3		4
5″	3¾		4
5″	3¾		3¾
5″	3¾		3½
5″	3⅞		3¾
5″	4½		4½
5″	4		3⅜
5″	2½		3
5″	4¼		4
5″	3¾		3¾
5″	3¾		3¼
5″	3½		3¾
5″	3		3¾
5″	3⅛		3½
5″	3¾		3¼
5″	4¼		4
5″	4¼		4¼
5″	3¼		3¼
5″	4¼		4
5″	4		3¾
5″	3¾		3⅞
5″	4		3¼
5″	4¼		3¼
5″	3½		3⅛
5″	3⅜		4

hold-downs at 2½″ ft. centers. Preplan the location and spacing of hold-downs. Keep in mind that the joints between voids are the weakest points in the whole system.

3. Keep hold-downs in place until vibration of concrete is complete. If the manufacturing procedure calls for earlier removal of hold-downs, do it only when the vibrators are at least 20 ft. from the hold-down to be removed to reduce the transmission of vibration through the cage.
4. Use small size vibrators.
5. Design the hold-down which consists of thin and slim elements—rods or plates—so that the cavities in the deck after removal of hold-downs can be filled with concrete in the easiest manner.

VOID FLOATATION IN CONCRETE

Void floatation in concrete has always been a problem. Concrete engineers have been looking for answers to this problem for years. Many attempts have been made to compute or assume the hydrostatic uplift force. Some engineers claim they have solved this problem, others are doubtful whether their approach or assumptions were correct.

As the void floatation problem is related to so many varying factors such as slump of concrete, amount of concrete around the void, vibration, sequence of pouring, size of void, quality of void, position, type and spacing of hold-downs, and some others, we can safely say that only through experimentation can we arrive at any satisfactory results.

There has been only one known test performed on a void in order to learn its characteristics during concrete placing and vibration operation, to find some kind of an answer to the floatation problem. The available information is incomplete and consequently some assumptions in calculations are necessary. Since the results are for one test only and since some assumptions were made, no generalization can be made to other cases.

On May 20, 1958, engineers from the Highway Department of the State of Kansas conducted a test to determine the amount of floatation or lift encountered when concrete was placed around and under voids.

For the test, a form 10 feet long, 26 inches wide and 26 inches deep was built. A 16″ x 16″ void 10 feet long (two 5 foot sections joined by an external sleeve) was placed in the form supported on both ends by chairs and held in the middle by a chair modified so that strain gauges could be attached. The void was strapped (¾″ straps, located on 54″ centers)

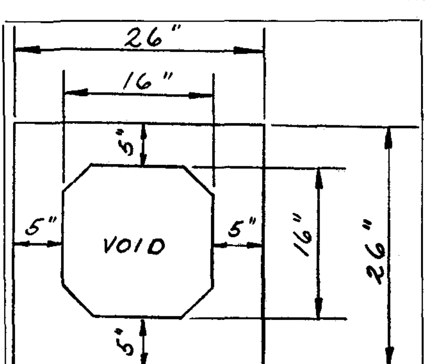


Fig. 40

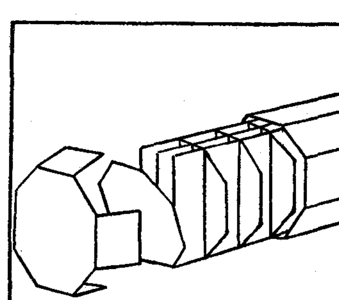


Fig. 41

securely to the chairs with the chairs bolted through the bottom of the form.

The void and reinforcing were positioned in the form prior to pouring. The concrete was placed on the top of the void and vibrated into position. Below are the results of this test.

Time	Vertical Load Lbs.	Tell Tales No 1	Tell Tales Mid 2	Tell Tales 30 3	Remarks
10:20	0	0	0	0	Just prior to placing concrete.
10:25	−410				Concrete heaped on tube.
	285				Concrete 12″-14″ deep vibration started.
	607				Concrete 12″-14″ deep vibrated end to end.
10:30	400				Concrete again heaped on tube.
	665				Concrete leveled, vibration started.
	920				Vibration continuing.
	1000				Vibrator running, all sides vibrated.
10:35	970				Vibration finished.
:39	807				
:43	709	15/16″	1/2″	3/4″	
:45	670				
:50	557	7/8″	7/16″	7/8″	
:55	520				
11:00	498				
:03	484				
:10	474				
:20	464				
:37	410				
:38	147				Anchor released on one side.
:39	20*	7/8″	7/16″	7/8″	Anchor released on both sides.

*This remaining 20 lbs. is about equal to the weight of of tubes which was supported by the chain.

Fig. 42

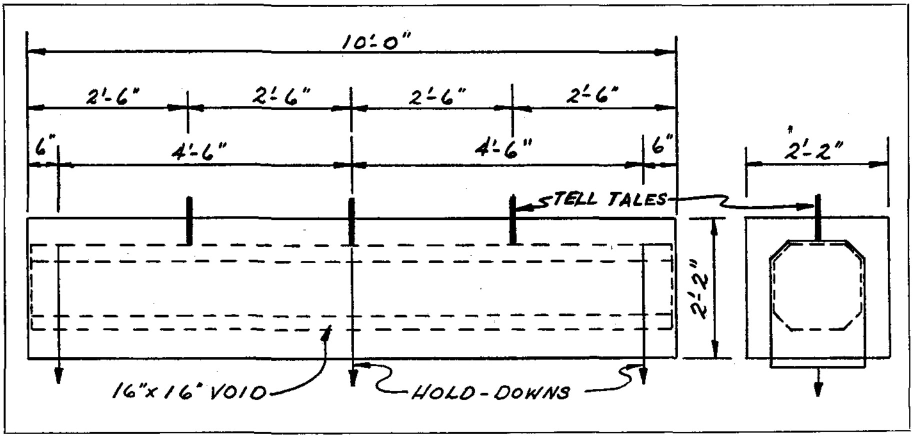


Fig. 43—Test set-up for data listed in Figure 42

Calculations:

Volume of void = 1.556 cu. ft./ft. x 10 ft. = 15.56 cu. ft.
Uplift force at center support = 1000 lb.
Assume ¼ of total uplift at each end support and ½ of total uplift at center support.
Total uplift = 2 x 1000 = 2000 lb.
Buoyancy 2000 lb./15.56 cu. ft. = 128.6 lb./cu. ft.
= 86% of hydrostatic uplift.

Deflection:

Measured at tell tales. Based on above assumption, the deflection at end supports is ½ of deflection at center support.

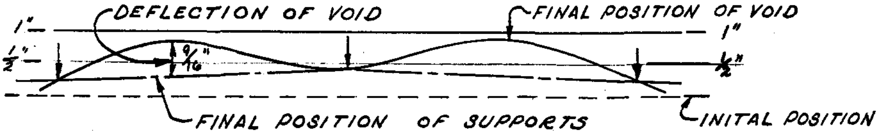


Fig. 44

Under full vibration, the uplift force was 128.6 lb./cu. ft. or 86% of the fluid hydrostatic uplift.

A maximum upward deflection of 7/8 in. was experienced. This deflection was both in the void and in yielding of the hold-down equipment. Separation of the deflections indicates an upward deflection of the void of 9/16 in. between supports.

TEMPERATURE AND AIR PRESSURE INSIDE THE VOID

Several tests were performed on voids in order to find the pattern of temperature rise of the air inside the void, as well as the relation of void air temperature to concrete temperature, and the air pressure inside the void.

In the past, many hollow slabs have been found with a hairline crack running down the length of the member. This is, in most instances, caused by air pressure which developed inside the void. This pressure is generated by the fresh hot concrete, and it is greatest just before the concrete gains tensile strength but is no longer fluid. Theory, as well as tests performed by some testing companies, proved that 0.5 psi of pressure is enough to cause a cracked surface in a 5″-thick top slab.

Past experience also shows that in many cases the fresh concrete in the top deck, forced by air pressure in the void, forms permanent deformation if allowed to set. This is particularly true in summer operations when concrete temperature rises much faster, developing higher air pressure in the void even before the concrete starts to set.

The writer performed a test in order to find the pattern of temperature rise and to calculate the air pressure in the void. An 8 ft.-long void, 39″ x 40″ in cross section, was set symmetrically in a 12 ft.-long 48″ x 48″ form. Two

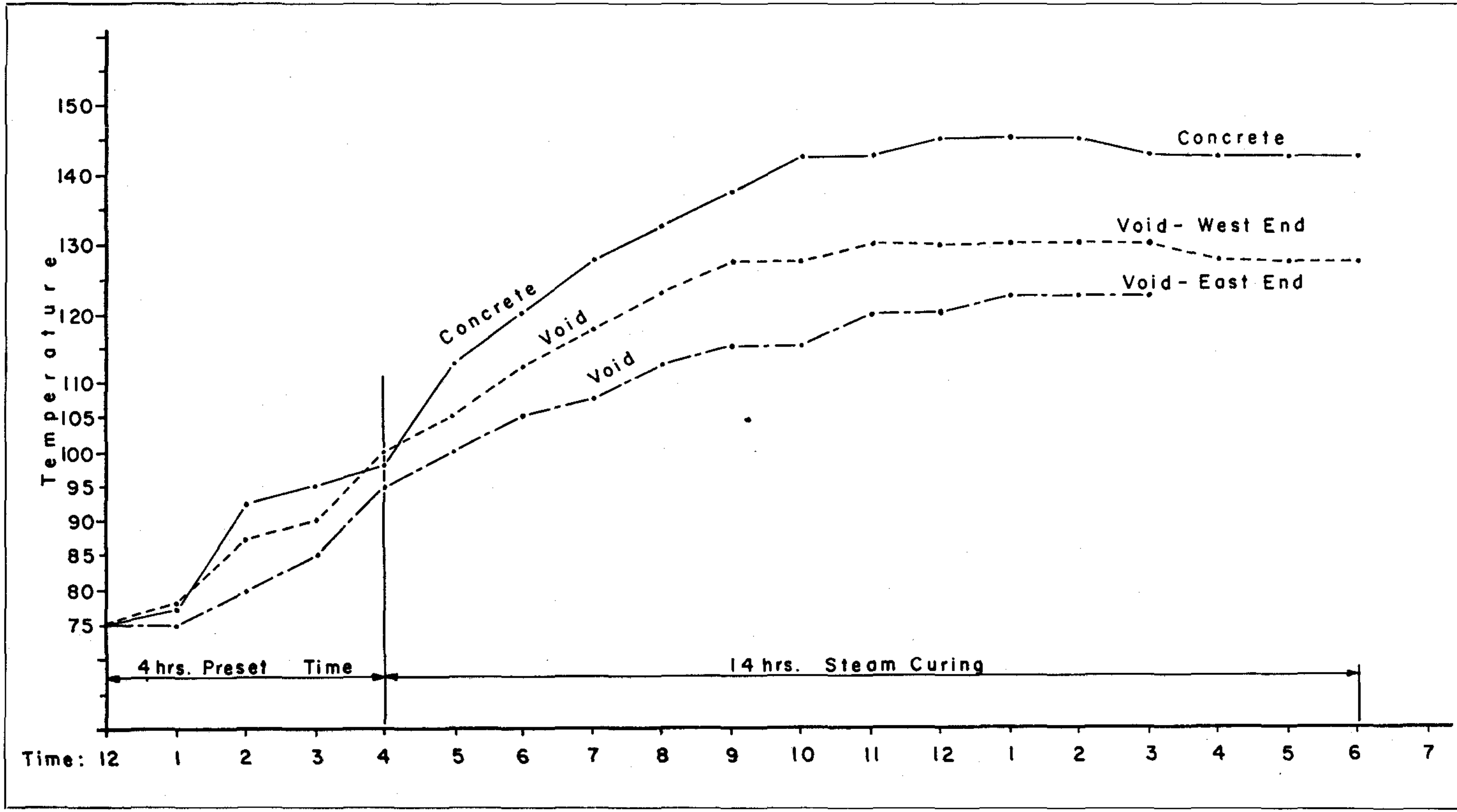


Fig. 45—Temperature Chart Showing Temperature Pattern Of Air Inside The Void And Concrete During Full Manufacturing Cycle.

recording thermometers were set in the void and one in the concrete. The void was not vented. Figure 46 shows the setup of the test.

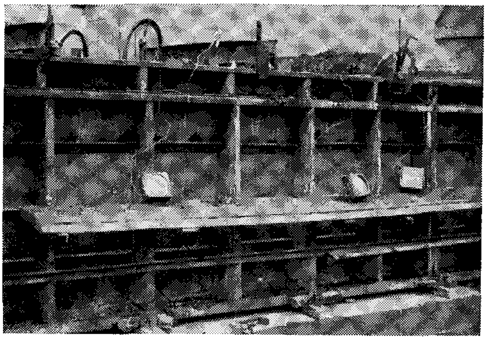


Fig. 46

The following calculations show that the temperature rise from 75°F up to 130°F in 11 hours had developed 1.64 psi pressure:

$$P_t = P_o\,(1 + \beta t) \qquad t = 75^\circ\text{F} = 23.8^\circ\text{C}$$
$$P_t = 14.7\ [1 + (0.00367) \longleftrightarrow (23.8)]$$
$$P_t = 14.7\ (1.0873)$$
$$P_t = 15.98 \text{ psi}$$

$$P_{tl} = 14.7\ [1 + (0.00367) \longleftrightarrow (54.0)] \qquad tl = 130^\circ\text{F} = 54^\circ\text{C}$$
$$P_{tl} = 14.7\ (1.1982)$$
$$P_{tl} = 17.62 \text{ psi}$$

$$17.62 - 15.98 = 1.64 \text{ psi}$$

Going through the same kind of calculations, the reader can find that in four hours the hydration has developed .76 psi (temperature rise from 75° to 100°) and in two hours developed .55 psi (temperature rise from 75° to 88°) air pressure in the void. This pressure obviously is dangerous and damaging at the early age of concrete, particularly in the summer, as well as when using high early (Type III) cement.

To eliminate the air pressure, it is recommended that a ½″, ¾″ or, maximum, 1″ tube (preferably plastic) be inserted into the void prior to pouring (or after pouring, as some producers do), and left in place as long as there is a possibility of damage from pressure. Venting of voids has become a standard practice in most prestressing plants throughout the country.

VENTING VOIDS

There is an unwritten rule in all prestress yards to release the air from the void. This is done, as shown in Figures 47 and 48, by puncturing the void with a sharp, ½ in. diameter rod and inserting a metal or plastic vent. The puncturng can be done either before placing concrete on top of the void or shortly after the concrete has been placed and finished. One vent per void is quite sufficient.

The next day, after the box slab has cooled off, the vent material can be removed and the hole filled up with mortar.

Fig. 47

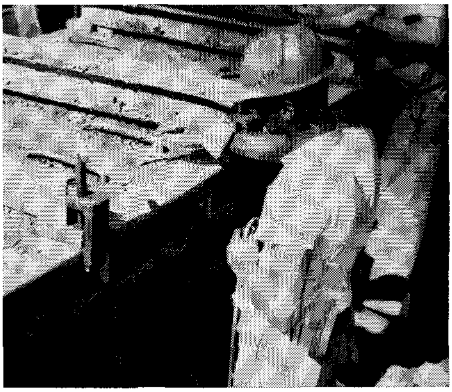


Fig. 48

WATER IN THE VOID

Some plants who perform water curing of box slabs are often faced with the problem of providing a void drain hole under the void.

Several methods have been suggested and tried out in the past. A reliable method, which proved to be quite successful at several plants, is shown in Fig. 49. This system works as follows:

1. Take rubber suction cup and stick it into ½"-diameter plastic or aluminum tube.
2. Place this tube with rubber suction cup in the form where required.
3. Take T-shaped hold-down made of reinforcing bars to suit the slab depth and push it inside the tube so that it bears on top of suction cup and on top of tube (through washer).
4. Clamp hold-down to side forms with C-clamps or other means.

5. Pour first layer of concrete.
6. Remove T-shaped hold-down and check the position of the plastic or aluminum tube.
7. Place voids and proceed with pouring of concrete.
8. Next day when the box slab is stripped, remove the suction cup and punch a hole in the void.

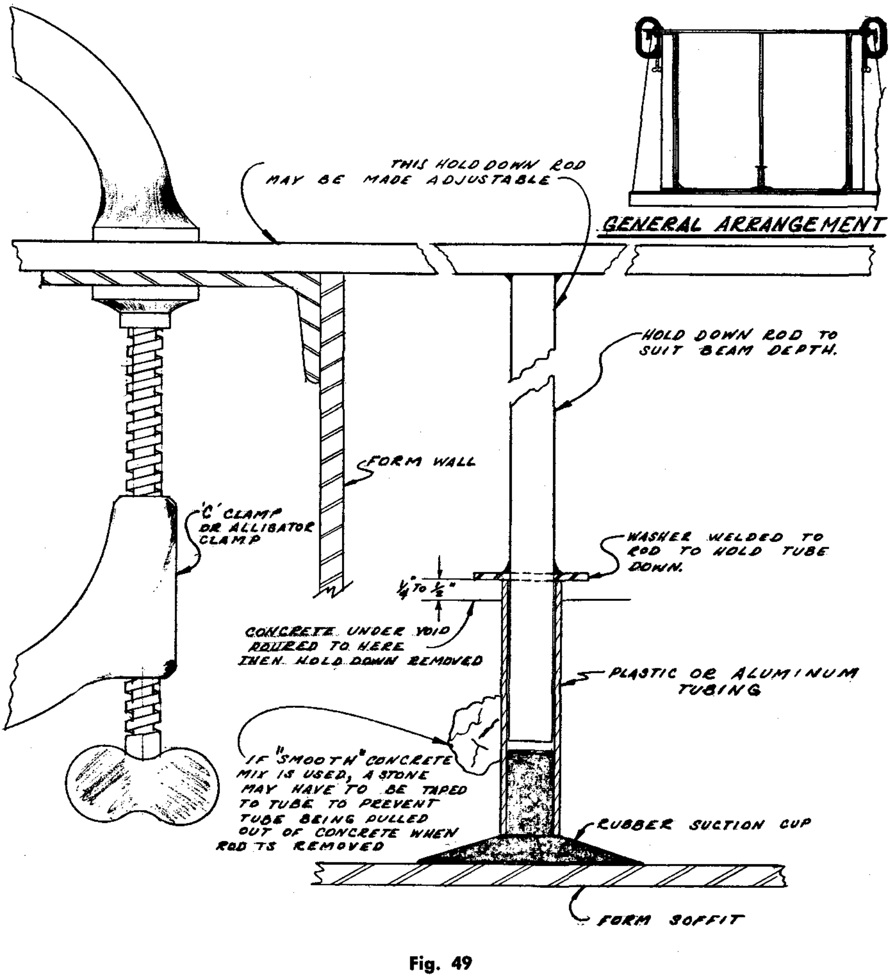


Fig. 49

When using the above method, two important principles have to be followed:

1. The drain tube has to be stiff. It could be made of stiff plastic, aluminum or steel; all of them are equally good.
2. Drain tube has to extend ¼″ above concrete surface. This helps to observe and check the position of the tube, as well as to provide good contact between tube and void.

The diameter of drain pipe is usually not less than ½″, up to maximum ⅝″. Only one drain per void is required.

VOID TOLERANCES

The tolerances for fabrication and placing of voids have never been established in our industry. In the last two or three years various highway commissions and municipalities tried to set some standards and specify final void tolerances or, rather, final web and flange thicknesses. But so far, neither manufacturers nor designers have arrived at any final conclusions or recommendations which could be universally agreed upon and adopted.

Designers and manufacturers in particular must realize that the strength of a box slab greatly depends upon the position of the void. By raising or otherwise displacing the void, the manufacturer is changing the characteristics and cross-sectional properties of the slab and, in some cases, can eventually reduce the live load considerably. The problem is that the designer does not know what the new properties are and how much they deviate from the computed ones. Therefore, it is very important that voids be placed and held in place exactly as called for on shop drawings.

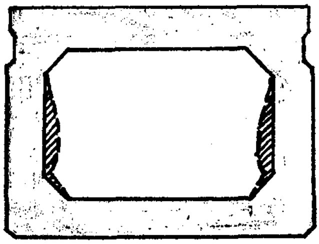
Since voids get heavy abuse during placing and concreting operations, one experienced man, preferably a foreman, should be assigned to inspect and check the voids and void hold-downs before and after the concrete is placed, to see that they are all in position as called for.

Naturally, it is impossible to produce anything without tolerances. High precision costs money and is an unnecessary luxury. This principle applies to box slabs as well. Therefore, it is more important to produce slabs within allowable tolerances which will not greatly affect the sectional properties, weight, or otherwise change the designer's intentions and design principles. But what are the allowable tolerances as far as the void is concerned?

Let us analyze the four major types of void displacement and how much this displacement affects the slab properties:

1. Displacement in vertical direction: the bottom layer of concrete (concrete under the void) will never be reduced in thickness. There is a chance that the thickness will slightly increase under the vibration and pressure, as the concrete will tend to pack or get under the void. The experiments indicate that this increase does not usually exceed ¼″ to ½″ under the most severe conditions, and this slight increase cannot affect the design seriously. The top layer of concrete can always be reduced in thickness because of void floatation. The reduced thickness of flange cuts section modulus at the top and may reduce the ultimate capacity in bending. It also reduces the capacity of the top flange, and local failure can occur. Floating or rising voids can also shift the reinforcement and reduce the concrete coverage over the reinforcing steel, and cause spalling and rusting

2. Displacement in horizontal direction: this can occur if the void is not secured against lateral shifting or movement and one web can be thinner than the other (for instance, 4″ and 6″ instead of 5″ on either side). Under this condition, the thinner side of the slab can be overstressed in shear, which may reduce the ultimate capacity of the section. Reinforcement (stirrups) also may not get the proper concrete coverage.



Partial collapse of the void (symmetrically on both sides of the slab as shown) can significantly increase the total weight of the slab, shift the neutral axis down and increase the stresses in the top flange.

Fig. 50

3. Rotation of the void can affect all four sides of the box, with the effects as described under Items 1 and 2 above.
4. Lengthwise displacement happens quite often. The movement does not exceed a couple of inches and can be easily corrected during concrete operations. If not corrected, such slight movement cannot affect the design at all.

Taking all the above facts into consideration, as well as the understanding of void behavior and the knowledge gained in many full-scale void tests, the following tolerances shown in Figure 51 are recommended as safe working tolerances for the final position of voids after the concrete has taken permanent set.

Weight increase should not exceed 6 percent over theoretical, (this is considered to be the total weight increase as a result of void deformations, higher strike-off of the member and slab width tolerance).

The above values are very close and, in some cases, exactly the same ones as recommended or specified by highway commissions or municipalities.

Naturally, not all void suppliers and not all box slab manufacturing plants are presently in a position to meet the above requirements. The manufacturers will need to re-evaluate their position as far as their "favorite" voids are concerned; get acquainted with the complete void market, available void materials and their characteristics; analyze manufacturing procedures and equipment; and select the best void and the best methods to meet the above requirements. There is no doubt that the industry can do that, and do it quite easily and in a fairly short time. Only then will we produce box slabs "in accordance with plans and specifications".

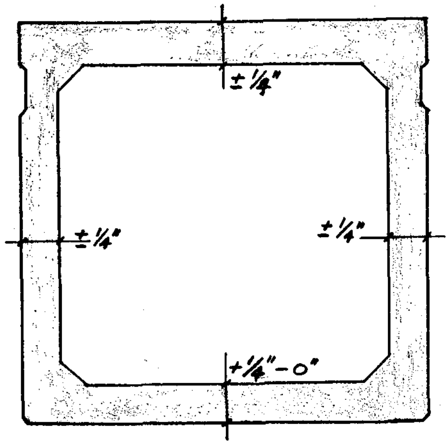


Fig. 51

DEVELOPING SPECIFICATIONS AND STANDARDS

In the early years of box slabs we had specified voids of corrugated cardboard material, having no understanding of its chemical and physical characteristics. And the voids were designed and supplied by people who didn't have any idea of our production needs and requirements. In the last 3 to 4 years both—the maker and the user—have learned a lot about each others products. Gaining more and more knowledge and experience with voids and observing void behavior and performance during promotion or in full size performance tests, void manufacturers were able to re-evaluate their designs and material and to come up with a number of improvements and new void designs. The results are very encouraging and promising.

And, furthermore, most void manufacturers have developed their own specifications and standards. This again is helping engineers to compare these standards of various brands and, by interpreting test results, they can also make conclusions for selection of the best voids. It still seems impossible today, but there is a hope that in the not too distant future the industry will be able to write uniform specifications for rectangular cardboard voids.

In going over the above analysis, it is quite evident that designing, making and using voids of corrugated fiberboard is a quite complex operation. While there always was and still is a great temptation to close the eyes to the many problems involved, every void user should welcome the opportunity to make as complete a study of "void problem" as possible because, as stressed in another chapter, once the void material is delivered to the plant, it is our full duty and responsibility to protect the voids and employ them properly so that they would fully serve their intended purpose.

The box slab specifying agency or the designer could eventually use the following suggested specifications:

"*Void Tubes for Box Slabs*—Void tubes or inside forms shall be as shown on the plans and shall be approved by the Engineer. They shall be composed of materials and shall be of a design that will enable them to withstand the forces imposed upon them during the fabrication of the slab without substantial deformation such as bulging, sagging or collapse.

The allowable tolerances shall be as follows: (See Fig. 51)

"Thickness of the bottom layer:	+¼″ & −0″
Thickness of the top flange:	+¼″ & −¼″
Web thickness:	+¼″ & −¼″
Tolerances lengthwise:	
Diaphragms	+1″ & −0″
Solid ends	+2″ & −1″
Rotation: (Should be included—not added—in the web thickness.)	+¼″ & −¼″

Weight increase shall not exceed 6 percent of theoretical, assuming that the weight of 1 cu. ft. of concrete is 150 lbs.

"In the case of void tubes offered for use which have not been shown to perform satisfactorily through prior use, a test section of slab, 10 ft. long (with 8 ft. long void butting against end bulkhead) shall be constructed to observe the behavior of the tube before approval is granted.

"Void tubes, if made of fibrous material, shall be protected against damage during storing and handling and shall be protected from moisture and water attack. Damaged void tubes shall not be used.

"Unless otherwise provided, all box slabs shall have void tube drains and air vents placed as shown on the plans. The forming of the drains and vents and the materials used for forming shall be approved by the Engineer. When no longer needed, the air vents shall be filled with a mortar."

SELECTION AND PURCHASING OF VOIDS

Selection and purchasing of voids is a very important function. In the past the selection of voids was based on manufacturers' promises or persuasion that their void "will do the job". In many instances the only local corrugated cardboard box manufacturer supplied the voids for the local box slab manufacturer and this business relationship was based on personal friendships.

As the first part of this report indicates that the selection of voids is very important business, it should definitely be based on engineering as well as performance factors to assure that the plant gets the best void for specific conditions.

The writer is of the opinion that the void should be selected by a qualified design or production engineer, working together with production superintendent and production personnel, to secure the best results. First, the person who selects the void has to be one-hundred percent familiar with the box slab he is going to produce, void requirements, void technology, and must possess good knowledge of the void market. And, furthermore, the person who selects the voids must have a working knowledge of void performance and must conduct at least one or two full-scale void tests in his own yard to observe the void behavior under different concrete pressures. Only then will the production engineer understand and get the feeling of void behavior and be in a position to make an intelligent decision based on sound theoretical principles and practical experience.

The selection of a void manufacturer should never be left with the purchasing agent, who does not have and will never have any knowledge of engineering or technical aspects of void material. The purchasing agent should be guided by the design or production engineer.

As far as voids are concerned, the price should not be the only consideration. It is true that prices of voids vary, but the spread between the price of lowest and highest bidder does not exceed 20 percent and cannot seriously affect the bid price of box slabs per lineal foot.

Past experience has shown that the tendency to try to shave a few pennies off the void price tremendously affected the manufacturing costs of slabs because of void failures, and instead of the expected additional profit, the plant lost money on the project. The situation in the Chicago area in 1960-61, as mentioned previously, is a very classic example to support this statement.

The other disadvantage in the past was that the void industry—at least 12 major corrugated cardboard manufacturers—has never established any void standards as far as corrugated cardboard paper and the interior design is concerned. This report has shown that these two considerations are very important for the void user—the prestressed industry. The writer, who has worked individually with all the major cardboard manufacturers, has encouraged them to establish their own standards and price lists as the initial step in developing proper relationships between the supplier and the user.

In establishing manufacturers' standards, the writer requested all void manufacturers to follow certain principles for each type of void:

1. Design of void—showing the construction of void transversally and longitudinally, outlining the spacing of partitions in each direction.
2. Optimum length of outer shell, as well as stating the minimum and maximum length of the void.
3. Length of interior partitions longitudinally.
4. Lapping method or joint relationship between outer shell and inner partitions.
5. Description of manufacturer's joint for the outer shell.
6. Manufacturing tolerances.
7. Type of corrugated paper.
8. Strength of corrugated paper, expressed in Mullen (pounds per square inch), for each part of the void.
9. Direction of corrugations.
10. Weight of corrugated cardboard in pounds per 1000 square feet.
11. Weight of void in pounds per lineal foot in finished product.
12. Kind of waterproof material used for glue or lamination purposes for corrugated cardboard components. This item also requests that they state the impregnation of the paper if that is the case.
13. Waterproofing coating material for outer shell and end caps.
14. Void assembling procedure.
15. Tools, accessories and equipment needed to assemble the voids.
16. Time required to assemble the void in minutes per lineal foot.

The void manufacturers followed this procedure more or less precisely and have established their void standards as outlined above. It is recommended that whenever someone purchases voids, the production engineer and purchasing agent should use these standards as the basis for purchase order or contract. The purchase will then be based on well-known facts and will benefit the void supplier and also legally protect them as well as the prestresser, who will know exactly what he is getting and paying for.

The procedure in purchasing voids should be arranged as follows:

1. After the engineer has selected the void manufacturer and the type of void for a specific job he should contact the manufacturer and request him to supply an 8′-long void section for a full-scale test in the prestresser's yard.
2. This test should be arranged following the specifications as outlined under "Void Testing," and the test results documented, photographed and evaluated.

3. If the void performs satisfactorily, the engineer should notify the purchasing agent to purchase the voids, giving him the complete list of specifications and requirements to follow.
4. If the void performs unsatisfactorily, the engineer should consider whether to continue his work with the same manufacturer, asking him to redesign the void or select stronger cardboard material or waterproofing material; or, if this is not possible, switch to another void manufacturer who can satisfy requirements. No void should be purchased on the basis of unsatisfactory test results.

After the voids are received, the production department should follow and strictly adhere to the recommendations made under "Void Technology", as far as storing, handling and placing of voids is concerned. Here again, it is needless to say that from the moment the delivery slip is signed, the void becomes user's property, and from that moment on, only he is responsible for what happens to the void.

DESIGNATIONS AND ABBREVIATIONS TYPICAL IN THE VOID INDUSTRY

SF	– Single Face
DF	– Double Face
DW	– Double Wall
NT	– Non Test
CC	– Corner Cut
DC	– Die Cut
CORR	– Corrugation
A	– A Flute
B	– B Flute
C	– C Flute
SL.	– Slot
SLTD.	– Slotted
SC.	– Score
SCD.	– Scored
SH.	– Sheet (As Sltd. Sh.–Slotted Sheet, etc.)
PC.	– Piece
PCS.	– Pieces
SPEC.	– Special (Also sometimes used to mean Specification.)
C/B Comb.	– Typcal symbol to represent flute combination for construction of double wall corrugated fibreboard (as C-Flute, B-Flute combination).
DSGN.	– Design
C.L.	– Centerline
SYM. C.L.	– Symmetrical about centerline
	Denotes Direction of flute in corrugated fibreboard
ST.	– Stitch
STCD	– Stitched
GL.	– Glue
GLD.	– Glued
BDL.	– Bundle
STK.	– Stack

STD.	– Standard
REG.	– Regular
O.D.	– Over-all or outside dimension
I.D.	– Inside dimension
ARRGD.	– Arranged
ARRGT.	– Arrangement
L TO R	– Left to Right
T TO B	– Top to Bottom

PART III

IMPORTANCE OF FULL-SCALE VOID TESTS

In earlier chapters it is mentioned that the only means of determining the void performance and behavior of the void components, as well as evaluating brands and different designs of voids, is full-scale testing in prestresser's yard. We have done a lot in this regard in the past but the only disadvantage was that nobody cared to document the void test and let the other people know of the test results. So, the knowledge of void performance or void design was kept within one plant, one department or one person. Naturally, the plant, the company, or even the industry did not benefit from this. On the other hand, the void testing was done sporadically as the need arose and the industry could never get a complete picture of the problem.

In 1961 the former Concrete Products Division of Martin Marietta Corporation decided to go into an elaborate testing program in order to find more facts about void behavior, as well as to evaluate different void designs and manufacturers. A specific void testing procedure was established and outlined to all the plants who were participating in this program. During the years of 1961 and 1962 at least 37 full-scale void tests were performed at different locations.

These tests opened a new era in our thinking and approach to the void problem. The tests show that the voids behave differently, depending on the design of the void and the type of corrugated paper used in its manufacture.

The results indicate that the lengthy and exhaustive work with void manufacturers in the scope of this program was very fruitful. The writer is confident that the void industry today can supply a void which will be perfect from all aspects—design, material and performance. It can also be stated that a void, properly designed by the void manufacturer and properly stored, handled and placed by plant personnel, can produce a perfect box slab within allowable tolerances.

PROPOSED VOID TESTING PROCEDURE

It is of utmost importance that our industry establish a specific void testing procedure. This will help both—our industry, to accumulate very important technical data on comparative basis in order to make sound judgments in the selection of void material, and the void industry, to evaluate test results and to design better voids. But the main concept in doing this would be to gain security in whatever we do with the voids.

The full-scale void testing procedure was arbitrarily established in 1961, and the last 37 tests proved it to be quite practical. In this procedure, the following steps have to be observed:

1. The manufacturer must provide an 8 ft.-long completely assembled void consisting of two 4 ft.-long separate voids joined together by any approved method (inner sleeve or outer sleeve, or other).
2. The void should be placed in a 10 ft-long form or mold whereby one end of the void would butt against the bulkhead, but at the other end, 2 ft. solid concrete section would be formed.
3. Two-and one-half-inch-slump concrete with approximate air content of 4-5% should be placed and vibrated with an internal vibrator in the usual manner to assimilate the normal working conditions as closely as possible.
4. Three hold-downs should be placed above the void to support it against the uplift. The spacing of hold-downs should be 3 ft., or 1 ft. from either end of the void. Figure 52 outlines the void testing setup.

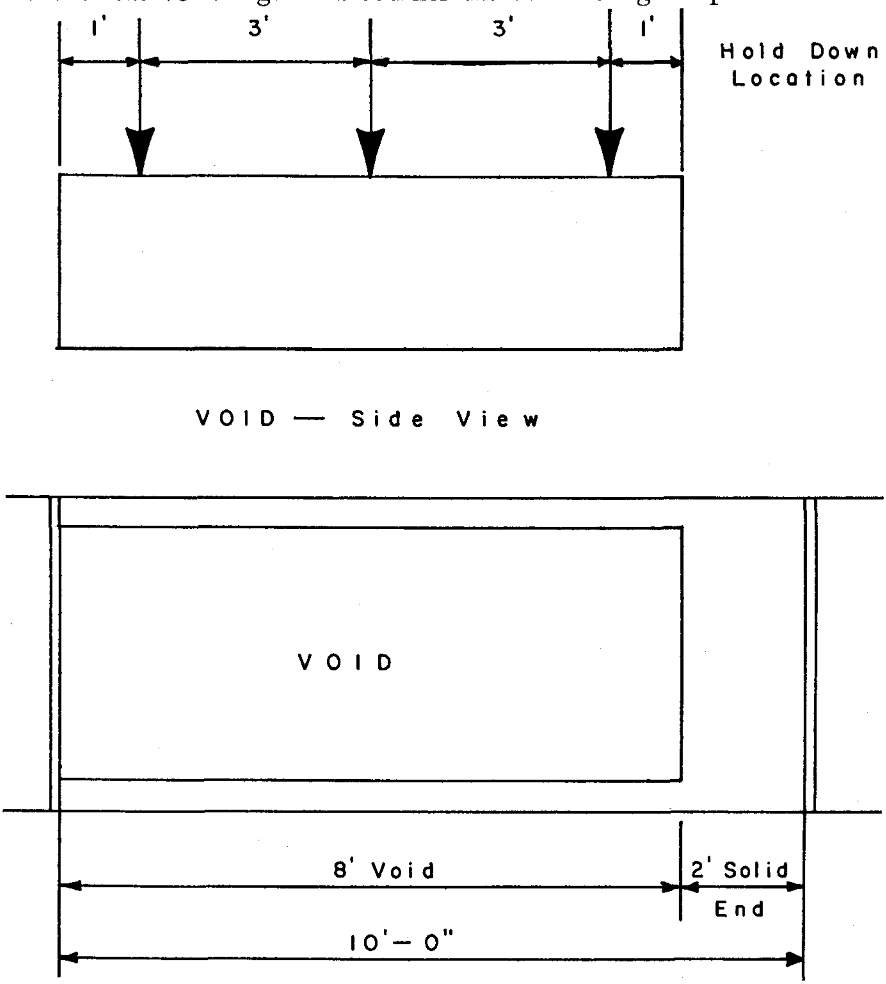


Fig. 52

5. Finishing and curing of concrete should be done under normal working conditions (includes steam curing).
6. Next day, after the concrete has reached 4000 psi (release strength) test should be removed from the stressing bed and placed in the storage yard.
7. Next step is to remove the void components and document all the observations:
   a. Extent of collapse of outer shell
   b. Deformations at sides, bottom, top and the end facing the solid concrete section
   c. Void deformations longitudinally between two hold-downs.
   d. Deformation of end cap
   e. Water content in the void
   f. Moisture penetration in the corrugated paper
   g. Any other unusual observations

All this information should be documented on a standard test report sheet as outlined in Figure 53 and the test data documented on the "test data sheet" as shown in Figure 54.

Fig. 53—Test Report Sheet

VOID TEST		TEST #
PLANT:	DATE POURED:	Date Stripped:
NAME OF VOID:	MANUFACTURER OF VOID	
VOID SIZE: Height Width Length	This test void consists of two equal sections, joined together. Void construction and test setup shown on Page 3.	

VOID MATERIAL:

a) Interior
b) Exterior
c) Coating
d) Interior Waterpr.

Stored: Inside, Outside

Kept in Storage for ________ Days

VOID SPECIFICATIONS:

a) Mullen Test
b) Crush Test
c) Column Test
d) Pin Adhesion Test

Humidity during Storage ________ %

VOID WEIGHT PER FOOT:

TIME OF ASSEMBLY:

TYPE OF HOLD-DOWN:

a) Prongs Resting on Void
b) Rebar Cage Holding the Void
c) Hold-Down Spacing

CONCRETE:

a) Mix Design
b) Strength
c) Slump
d) Air

CURING:

a) Steam Preset time _____ hrs; steam _____ hrs; $t =$ _____F°
b) Water
c) Other Method
d) No Curing

WEATHER CONDITIONS DURING TESTING:

a) Sunny Cloudy Riny
b) Temperature
c) Humidity

VOID WAS OR WAS NOT PRECONDITIONED

OTHER NOTES:

OBSERVATIONS:

WATER ABSORPTION WHEN STRIPPED
a) Dry b) Wet c) Soaked
d) Describe

NOTICEABLE COLLAPSE:

DEFORMATIONS:

FLOATATION:

ROTATION:

UNUSUAL OCCURENCE OR BEHAVIOR:

PERCENT INCREASED WEIGHT OF BEAM:

OTHER OBSERVATIONS:

REMARKS AND CONCLUSIONS:

Test Conducted by:	Witness:	Date

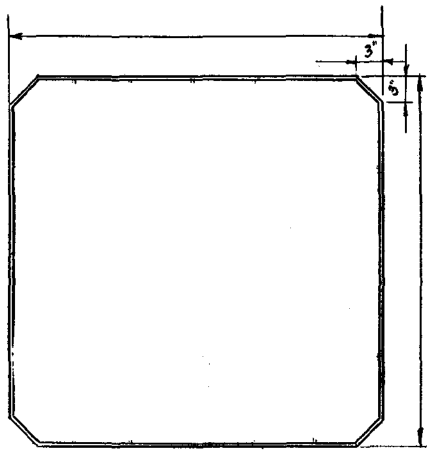
Fig. 53—Test Report Sheet Continued

It is very important to have the void manufacturer present to witness the test, as well as engineering and production personnel, including superintendent and all foremen. The educational aspects of full-scale void testing should not be overlooked. Void testing is the only means of fully demonstrating to the production personnel what happens to the void under different working conditions, where the danger is involved in using corrugated cardboard voids, what should be done to expect best results from the void, and how it should be done.

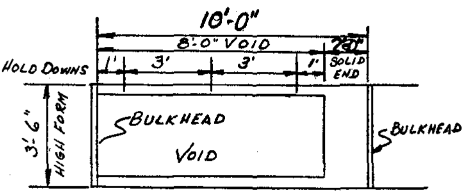
There is a great need to establish an industry-wide standard testing procedure for voids. The writer suggests that the Prestressed Concrete Institute should propose to the whole industry such a uniform void testing procedure as applicable and binding to all manufacturers. This testing procedure eventually could also be adopted as a PCI standard, or even better, it should become an ASTM standard to gain highest respect from all the people concerned.

The writer is also of the opinion that any box beam specifying agency

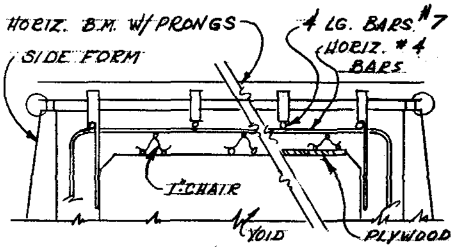
PLACE TEST PICTURE HERE



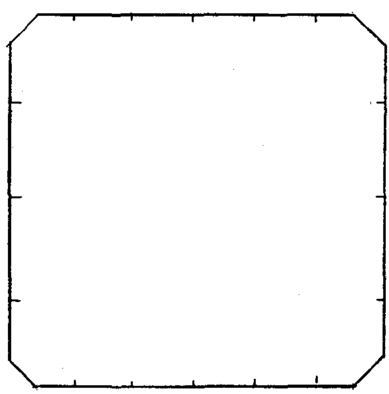
SHELL AND FRAME



SIDE VIEW



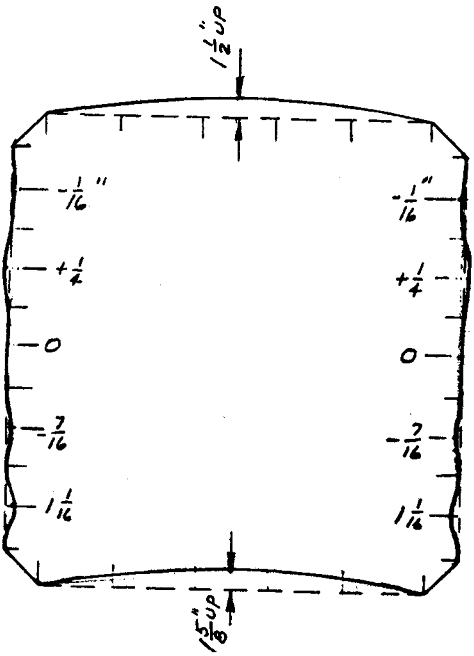
VOID HOLD-DOWN W/ W.O. PLYWOOD



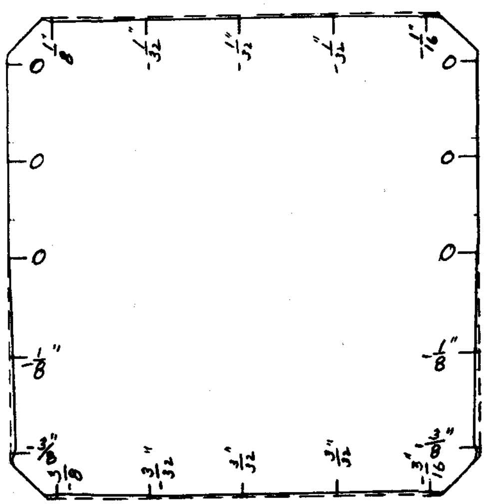
DEFORMATION DATA

Test Data Sheet Fig. 54

TYPICAL VOID DEFORMATIONS:

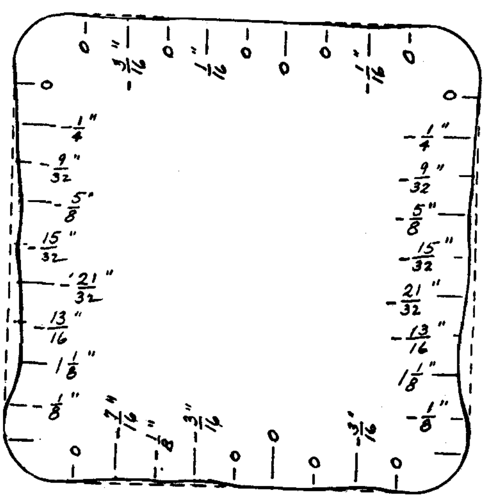


CASE A

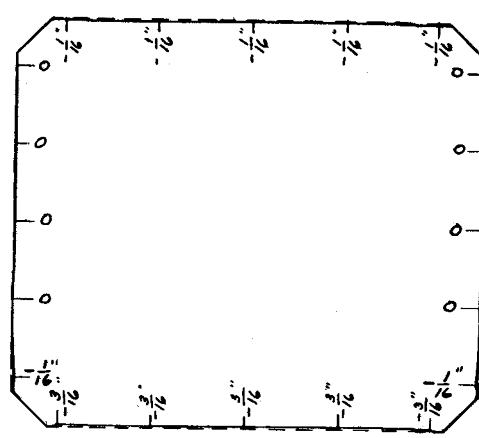


CASE B

CASE A shows a cardboard void near collapse. This void had egg-crate interiors. Only outside shell was coated with waterproof material.
CASE B: Same void as in Case A. However all of the void material was preconditioned on the previous day in such a way that at the time of concrete placing the relative humidity in the cardboard in the void was 50%. To achieve this, the whole void was fully wrapped in a polyethylene sheet.



CASE C



CASE D

CASE C: Typical deformations in voids made of hardboard shells with wood crate partitions, or in voids made of corrugated cardboard egg-crate partitions and hardboard shells.
CASE D: This void was made of asphalt impregnated corrugated paper.

should include a clause in their specifications that the void material should be tested in accordance with proposed or adopted PCI or ASTM testing procedures and specifications before each job.

The next logical step would be the certification of void plants, standards and void manufacturers.

In order to achieve that, I also propose the immediate establishment of a PCI technical subcommittee on "Voids in Box Slabs" consisting of five members—one PCI representative, two void industry representatives and two prestressed industry representatives—dealing with problems covered and recommendations proposed in this paper.

SUMMARY OF TEST RESULTS AND EVALUATION OF TESTS

Full-scale void tests have proved the following facts:

1. The humidity and water attack to the corrugated cardboard reduces the strength of the board and the void loses its effectiveness as far as performance is concerned.
2. Voids made of waterproof and/or humidity-resistant cardboard produce very satisfactory results compared to voids made of regular cardboard.
3. Not the strength of board (expressed in Mullen), but the humidity content in the cardboard and void and the time of exposure to high humidity are the only important factors: voids with lower strength board in lower humidity behave better than voids with high-strength board in high humidity media.
4. Many tests clearly and undisputedly proved the theory of the relative humidity content in the void material and the void: the closer it is to the ideal level, the better performance we can expect.
5. Taped joints provide better results than exposed ones. This finding applies to the manufacturer's joint as well.
6. Hold-down system employing hold-down prongs resting on the rebar cage which in turn is supported on continuous rebar bolsters sitting on top of the void, is superior to hold-down system with prongs resting directly on top of the void.
7. After removal of hold-downs, voids tend to float. This floatation does not exceed ¼" in average, reaching ⅜" in some cases.
8. Where water curing of box slabs is used, draining the void is advisable.
9. In cases where hold-down systems employ hold-down prongs resting directly on top of the void, the hold-down spacing should be reduced to 2 ft. or even less.
10. In cases where hold-down systems employ hold-down prongs supporting rebar cage and bar bolsters, the hold-down spacing can be extended to 3 ft.
11. A permanent void hold-down eliminates any void movement in the slab during concrete operations and after.
12. Voids with tight fit of interior partitions behave better than voids with loose fit.
13. All the tests proved the fact that it is very important to follow the

recommendations made regarding delivery, assembling, handling and placing of voids as outlined in this paper.

PART IV

CONCLUSIONS AND RECOMMENDATIONS

In the initial chapters of this report some sad facts about past experiences with voids were stated. Void collapse and overweight of box beams have bothered our industry for many years. In concluding this report, and after having done two years of investigation and research on this unusual material, I can state the latest facts which occurred in the industry as the result of this work. One well-known manufacturing company who used one of the voids described in this report, whereby the void manufacturer strictly adhered to the theory and recommendations expressed in this report, has obtained excellent end results. This manufacturer produced approximately 120 box slabs for a large overpass project composed of 100 ft.-long slabs 48" x 48" in cross section. The tolerances in these beams were of utmost importance—inspectors were checking the thickness of side walls, bottom and top slab of each beam, and the beams were weighed in order to find the overweight. After 28 beams were weighed, the inspectors dropped the weighing as an unnecessary operation because none of the 28 box beams exceeded the overweight of 1%.

Another manufacturer has produced four through-void box beams for the PCI as a part of the AREA trestle bridge testing program. These beams show perfect workmanship.

These facts give the writer absolutely full confidence in stating that today the industry can produce box beams to the full satisfaction of our customers.

A lot of work has been done in the void industry in the last two years. It is a good indication that even more can be accomplished in the years to come.

There is no doubt that all engineers and production personnel engaged in the design and manufacture of box beams will be quite concerned about their void problems after they read this report. In many plants the situation is not at all critical. With a minimum of effort and an openminded approach, most of the problems can be eliminated almost overnight. But, certainly, there are a number of plants and a group of people who will need to change their whole concept of thinking and work hard in order to learn and understand the principles and new methods in employing voids properly. Part II, III and IV of this report should prove to be of great value to them.

The so-called "void problem" applies to the whole precast industry. The success or failure of one concrete producer reflects to the success or failure of his competitor, and vice versa. Therefore, box beams, with the related void problem, should be approached by the entire prestressed concrete industry in an organized manner. All box beam manufacturers should be taught how to select, test, purchase, transport, store and handle corrugated cardboard voids, and the Prestressed Concrete Institute, as the spokesman for the industry, should assume the responsibility and duty of informing all the manufacturers of the box beam situation and take the lead in correcting it.

WHAT SHOULD THE PRESTRESSED CONCRETE INDUSTRY DO IN THE FUTURE CONCERNING BOX BEAMS AND CARDBOARD VOIDS?

1. As far as *research* is concerned, we should:
   a. Devote more time and money for testing and research purposes.
   b. Adopt testing standards which would be uniform for the whole industry. Also collaborate with PCI and ASTM in establishing void testing standards.
   c. Proceed with actual testing and research with different manufacturers and brands of voids. Document test results and publish them; with the results to be made available to the whole industry.
   d. Research engineers should make sound recommendations regarding the design and selection of voids.
2. As far as *engineering* is concerned, we should:
   a. Cooperate with research engineers in void testing.
   b. Finalize establishment of void standards and specifications.
   c. Explore the void industry in further search for new, better or more economical void material.
   d. Establish good liaison with present void suppliers and educate them in concrete problems and void performance requirements.
   e. Design and develop standards for thru voided box beams.
3. As far as *purchasing* is concerned, we should:
   a. Direct and guide the purchasing agents in the selection of void material.
   b. Involve purchasing agents in the search for better material.
   c. Indoctrinate the purchasing agents with the fact that low void price is not the only criterion in the purchase of voids.
4. As far as *production* is concerned, we should:
   a. Educate and train personnel—engineers, superintendents, foremen, and even more important, the laborers working on voids.
   b. Adopt sound manufacturing standards. Manufacturing procedures concerning voids should be worked out in detail and all personnel should adhere to them rigidly.
   c. Adopt sound quality control standards. Checking of void performance and measuring tolerances should become standard practice in the industry.
   d. Establish good reporting system so that all company personnel can learn of advances or failures simultaneously.
5. As far as *sales* are concerned, these individuals should carry the burden in connection with outside contacts. They should:
   a. Establish working cooperation with competitors—whether directly or through local or state prestress manufacturers associations—in order to promote the idea of using better voids and establishing uniform, industry-wide standards.
   b. Establish cooperation with the PCI and engage this organization in developing and promoting our ideas. Their current publications should be engaged and utilized in our mutual work.

c. After necessary advancements have been made in this area the cooperation and guidance of BPR should be sought.

There are many means at our industry's disposal for handling this problem. If properly handled and backed up with sufficient activity and enthusiasm, I am fully confident that the industry will increase box slab sales, and utilize the large investment in forms, beds and equipment.