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THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

Manly Vale, N.S.W., Australia

REPORT No. 79

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HYDRAULIC MODEL INVESTIGATION OF KERB-OPENING INLETS

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Report submitted to the Housing Commission of New South Wales, April 1965.

Preface.

The Housing Commission of New South Wales constructs, as a component of the housing programme, many miles of kerb and gutter in residential streets. The designs of these are the Commission's responsibility.

To obtain data for the improvement of kerb opening inlets, the Commission requested the Water Research Laboratory to determine, by means of model tests, the effectiveness of slot inlets for diverting water from gutters to sub surface drains, at various gutter gradients and depths of flow. The first series of tests was restricted to a depth of four inches of water at the gutter invert. This was arbitrarily called "gutter running full" condition. Subsequently, the tests were extended to determine the maximum discharge passing through the slot with no by-pass discharge downstream of the slot for various gutter gradients.

The model was built in September 1964 and tests were carried on intermittently until January 1965. The tests were conducted under the supervision of Mrs. D. M. Stone, Projects Officer, with Mr. Woodland serving as liaison officer between the Housing Commission and the Water Research Laboratory. The comment and advice of Messrs. Holmes and Giszar during visits of inspection of the work in progress is also acknowledged with appreciation.

R. T. Hattersley,
Senior Lecturer in Civil Engineering,
Officer-in-Charge.

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Summary

An hydraulic model study was carried out at the Water Research Laboratory of the standard kerb-opening inlet adopted by the Housing Commission of New South Wales and of some modified version of the standard inlet. The purpose of the study was to determine the efficiency of the inlet. Tests were conducted for the following cases:-

(i) Kerb-opening inlet (original Housing Commission design)

(ii) Kerb-opening inlet with length of gutter transition increased from 4 ft. to 8 ft.

(iii) Kerb-opening inlet with recess in kerb, and

(iv) Kerb-opening inlet with recess in kerb and deflectors in gutter.

Test results, which are compared in this report, show that the kerb-opening inlet with deflectors in the gutter proved to be the most efficient. Other modifications resulted in insignificant changes in efficiency by comparison with the standard design.

1. Introduction

1.1 The Prototype

The Housing Commission of New South Wales, in the course of developing extensive new housing schemes, is charged with the responsibility of the design and construction of the street systems serving these estates and the surface drainage of the areas.

A standard type of kerb inlet to divert water from street gutters to subsurface drains has been evolved as shown generally in Figure 1.

1.2 Purpose of Model Investigation

The hydraulic efficiency of such an inlet is expressible as the ratio of diverted flow to total flow in the gutter upstream of the kerb inlet. An hydraulic model study of the inlet was made to determine efficiency in relation to the form of the inlet and the gradient of the serving gutter.

1.3 Conditions of the Tests

Throughout the tests the cross slope of the adjacent roadway pavement, forming part of the boundary of the waterway, was maintained constant. The longitudinal slope of the gutter was varied within limits 0.5 pc. to 15 pc.

The height of the standard kerb inlet is 6 inches but an arbitrary depth of 4 inches was fixed as the "gutter running full" condition and efficiencies were measured under this condition for an inlet conforming to the design in Figure 1. Subsequently, variations were made to the form of the model as follows:-

(a) Length of transition to depressed section.

(b) Recess in the kerb varied over the transition length.

(c) Slots formed in the gutter to deflect the flow towards the inlet.

Measurements were also made of the maximum water depth at which the entire flow would be diverted.

All dimensions appearing in this report refer to the prototype unless otherwise specified.

2. The Model

2.1 General Description

A wooden street model 15 ft. long and 3 ft. wide was built in the laboratory. The model had a constant cross slope of 1:32 for pavement and 1:12 for the gutter, except for a depression across the gutter at the inlet. The surfaces of the pavement and gutter were painted to simulate prototype roughness. The inlet was installed at about 11 ft. downstream from the upstream end of the street model. The upstream end of the street model was hinged at the inlet chamber and the downstream end was hung from wooden pulley blocks supported by a scaffolding frame. This arrangement provided a means for adjusting to various gutter slopes. Figure 2 shows a photograph of the model in use. The general layout of the model is shown in Figure 3.

2.2 Model Scales

The choice of model scale depends upon such factors as scale effects, available water supply, accuracy required, available space and cost. After careful consideration had been given to the above factors, a natural linear scale of 1:4 was chosen. The scale gave a half street model 3 ft. wide. Since supercritical flow would prevail throughout the tests, consideration had also to be given to such factors as entry conditions, exit conditions and the minimum length required to ensure uniform flow near the kerb inlet. A street model 15 ft. long and 3 ft. wide was considered adequate to satisfy the above requirements. At the entry end, a proportional weir was installed to distribute the flow evenly into the street model. The flow over the proportional weir then passed through a "hexcel" (honeycomb) flow straightener into the street model. This arrangement had the effect of damping out certain shock waves generated at the entry and at the same time ensured a fairly uniform flow at the test section. Wind interference occurred at times during the test, but when the effect of the wind appeared significant testing was temporarily abandoned. The exit end was located a sufficient distance downstream of the test section to avoid interference by drawdown at the exit on the upstream sections.

Since gravity is the predominant force controlling fluid motion in both the model and prototype, model scales are given by Froudian relationships as follows:-

Depth scale (L_r) = 1:4
Horizontal scale (L_r) = 1:4
Discharge scale (Q_r) = $L_r^{2.50}$ = 1:32

To approximate the effect of roughness of the pavement and gutter, calculations were made using the Manning equation as the best available approach under the conditions of this series of tests.

$$n_r = \frac{n_m}{n_p} = L_r^{1/6}$$

where n_r = roughness scale

n_m = roughness in model

n_p = roughness in prototype

L_r = linear scale

For $L_r = 1/4$

$$n_r = L_r^{1/6} = 0.794$$

An estimate of the prototype roughness and the corresponding model roughness is given in Table 1.

Table 1.

Prototype and Model Roughnesses.

Material	Prototype Roughness n_p	Corresponding Model Roughness n_m
Hot mix (bitumen)	0.018	0.0143
	0.016	0.0127
concrete	0.015	0.0119
	0.014	0.011

Painted wood was used in the model. This has a roughness (n) varying from 0.011 to 0.012. This value approximately satisfied the required roughness to be used in the model.

3. Model Tests

3.1 Test Procedure

Flow was introduced into the inlet chamber from an 8 inch diameter supply line with orifice meter to measure the total flow. The flow in the inlet chamber passed over a proportional weir and then through the "hexcel" flow straightener into the street model.

The flow from the kerb-opening inlet was directed into the measuring flume by means of a chute and was measured by a 90^{o} V-notch weir. The by-passing flow was discharged into an existing channel flowing to waste.

Model tests were required for a specified depth of flow at the gutter, namely 1 inch depth in the model equivalent to 4 inches depth in the prototype. The depth of flow was measured by a point gauge located far enough upstream of the inlet to measure at a section of uniform flow. Because of the characteristic wavy water surface experienced with the prevailing supercritical flow, difficulty was experienced in maintaining a constant depth of one inch of flow at the gutter. Tests were conducted at depths of flow in the model 0.95 inches and 1.05 inches to study the effects of variation in depth. It was found that the change of depth had a marked effect on the efficiency of the inlet. This effect can be seen in Figure 8, the variation in efficiency ranging from 66 to 83 pc. at gutter slope of 1 pc. and from 9 to 14 pc. at gutter slope of 15 pc. The average flow at these two depths of flow was taken as the flow at depth of one inch. The critical nature of effect of change of depth on the efficiency of the inlet underlay the difficulty experienced in maintaining a constant depth of one inch of flow at the gutter by the point gauge. Depth measurement therefore could not serve as a basis for comparison of the results obtained for the various inlet designs.

Measuring total flow by orifice meter at the measured gutter slope as basis for comparison was considered adequate because the flow could be easily measured and at the same time much higher accuracy could be obtained.

In open channel flow, the Manning equation is valid only so long as the flow is proportional to the square root of slope. If the equation is plotted on a log-log scale, it would represent a line with a slope of 2:1. Verification tests were conducted on the model. The results obtained when plotted on log-log scale did not represent a line with a slope of 2:1. Tests were performed at depths of flow of 0.95 inches and 1.05 inches (model) to study this phenomenon. The total flow in the gutter at each depth of flow was plotted against the gutter slope on a log-log scale. Interpolation was made to draw a best-fit line which would represent the flow at one inch depth. The results together with those of Baltimore (Ref. 1) were plotted as shown in Figure 13. It was evident that neither the results at this laboratory nor the results at Baltimore closely followed a 2:1 slope line. Investigation of these interesting anomalies was not further pursued as use of the interpolated line as a basis for conducting tests was considered adequate for the purposes of this study. The discharge corresponding to any gutter slope was chosen from the experimentally determined curve in Figure 13. For comparison, the depth of flow was measured each time a test was made.

The longitudinal slope (gutter slope) was set by a dumpy level before a test was made. The cross-slope was checked by an abney level from time to time to make sure that the slope was maintained at a constant value (that is, 1:32 for the pavement and 1:12 for the gutter, with a depression at the inlet).

Model discharges ranged from 0.06 c.f.s. to 0.70 c.f.s. (1.92 c.f.s. to 22.4 c.f.s. prototype). The former value corresponded to low slope (0.5 pc) and the latter to high slope (15 pc). The depth of flow at the gutter varied from 0.92 inches to 1.16 inches (3.68 inches to 4.64 inches prototype).

3.2 Test Results

Figure 4 shows the arrangement of kerb-opening inlet first tested. This is the original design for the Housing Commission standard kerb-opening inlet. The results obtained are plotted in Figure 11. The range of discharge used was from 1.92 c.f.s. to 22.4 c.f.s. and the depth variation was from 3.80 inches to 4.20 inches.

The arrangement shown in Figure 5 corresponds to kerb-opening inlet with increase in length of gutter transition from 4 ft. to 8 ft. The results are plotted in Figure 11. During the first series of tests, there was a splash-in effect at the downstream end of the inlet. This was due to the fact that when flow hit the downstream end of the inlet, a fair amount of water splashed back into the gutter instead of into the inlet. The second series of tests was made with rounded and square corner at downstream end of the inlet to see whether the square corner would reduce the splash-in effect and increase the efficiency of the inlet. These results are plotted in Figure 9. The range of discharge was from 4.04 c.f.s. to 18.88 c.f.s. and the depth variation from 3.68 inches to 4.32 inches.

Figure 6 shows the arrangement of kerb-opening inlet with recess in the kerb. Test results are plotted in Figure 11. The range of discharges was from 2.88 c.f.s. to 18.24 c.f.s. and the depth variation from 3.68 inches to 3.96 inches.

The fourth and last series of tests was made for the arrangement of kerb-opening inlet with deflectors in the gutter as shown in Figure 7. This deflector inlet was tested with and without recess in the kerb. The results are plotted in Figure 10 for the purpose of comparison. The average of these two curves is plotted in Figure 11. The range of discharges was from 2.56 c.f.s. to 19.20 c.f.s. and the depth variation from 3.68 inches to 4.64 inches.

In addition to the above investigation, another series of tests was conducted to find out the discharge into the inlet for zero - bypass at different gutter slopes. The tests were only carried out for the arrangements of kerb-opening inlet with modifications because the original inlet was modified before this item was required to be included in the investigation. The results are given in Tables 2, 3 and 4, and are also plotted in Figure 12 for comparison.

Table 2.

Discharge into kerb-opening inlet for zero-bypass - for 8 ft. transition length.

Gutter slope in per cent	Discharge in c.f.s.	Depth of flow at gutter in inches
15.20	0.01 x 32 = 0.32	0.25 x 4 = 1.00
11.60	0.012 x 32 = 0.38	0.28 x 4 = 1.12
6.00	0.020 x 32 = 0.64	0.40 x 4 = 1.60
3.70	0.032 x 32 = 1.02	0.45 x 4 = 1.80
1.35	0.044 x 32 = 1.40	0.71 x 4 = 2.14

Table 3.

Discharge into kerb-opening inlet for zero-bypass - recess in kerb.

Gutter slope in per cent	Discharge in c.f.s.	Depth of flow at gutter in inches
15	0.014 x 32 = 0.45	0.34 x 4 = 1.36
12.30	0.016 x 32 = 0.51	0.36 x 4 = 1.44
9.60	0.018 x 32 = 0.58	0.38 x 4 = 1.52
8.00	0.020 x 32 = 0.64	0.42 x 4 = 1.68
5.40	0.022 x 32 = 0.70	0.46 x 4 = 1.84
3.50	0.024 x 32 = 0.77	0.51 x 4 = 2.04
2.00	0.045 x 32 = 1.44	0.55 x 4 = 2.20
1.00	0.052 x 32 = 1.67	0.77 x 4 = 3.08
0.50	0.06 x 32 = 1.92	0.85 x 4 = 3.40

Table 4.

Discharge into kerb-opening inlet for zero-bypass - deflection in gutter.

Gutter slope in per cent	Discharge in c.f.s.	Depth of flow at gutter in inches
16	0.048 x 32 = 1.54	0.48 x 4 = 1.92
13.65	0.082 x 32 = 1.67	0.56 x 4 = 2.24
11.36	0.056 x 32 = 1.79	0.56 x 4 = 2.24
8.50	0.054 x 32 = 1.73	0.58 x 4 = 2.32
6.60	0.06 x 32 = 1.92	0.62 x 4 = 2.48
4.60	6.058 x 32 = 1.86	0.64 x 4 = 2.56
2.85	0.056 x 32 = 1.79	0.68 x 4 = 2.72
0.70	0.05 x 32 = 1.60	0.87 x 4 = 3.48

4. Discussion of Results

As is evident in Figure 8, the variation in depth of flow at gutter was so critical that it was not desirable to use constant depth of flow at gutter as a basis to conduct the model tests. The use of total flow in gutter as a basis to run the whole series of tests is considered adequate because total flow is easy to measure with accuracy.

The splash-in effect experienced at the downstream end of the inlet during the course of testing was reduced appreciably by installing a square corner, but the efficiency of the inlet was not significantly increased. This is evident by reference to Figure 9.

Figure 10 shows the results for a deflector inlet with and without recess in the kerb. It is quite clear that, within the limits of experimental accuracy, these two curves can be considered almost the same. This implies that not much benefit would be gained by putting a recess in the kerb for this particular type of inlet.

For an overall comparison, reference is made to Figure 11, which shows the results of the four cases tested. It is obvious that the deflector inlet has a higher efficiency than the other three types. This is particularly true for gutter slopes greater than 4 pc. The kerb-opening inlet with recess in the kerb does not yield results far better than the results the original kerb-opening inlet yields. For gutter slopes greater than 5 pc., slight increase in efficiency is evident, but there is a decrease in efficiency for gutter slopes less than 5 pc. For the case of modifications in gutter transition, an increase in efficiency for gutter slopes greater than 5 pc. is also evident, and there is a tendency to decrease in efficiency for gutter slopes less than 5 pc. as compared with the results of the original kerb-opening inlet. However, within experimental accuracy, the above two modifications in kerb-opening inlet yield results which can be considered the same as the results of the original kerb-opening inlet.

Figure 12 shows the results of the maximum discharge into the kerb-opening inlet with zero-bypass at different gutter slopes. For the deflector inlet, though the points plotted appear to be rather scattered, it can probably be said that the maximum flow into the inlet at zero bypass tends to be independent of gutter slope with a value of about 1.75 c.f.s. It is also evident from Figure 12 that the inlet with deflectors diverts a much larger amount of flow than the other two types. As for the kerb-opening inlets with 8 feet transition length and with recess in the kerb, both have a general trend of increasing maximum flow into the inlet at zero bypass with decreasing gutter slope. For a given slope, the kerb-opening inlet with 8 ft. transition length has a lower maximum discharge than the kerb-opening inlet with recess in kerb.

5. Conclusions

Conclusions can be drawn as follows:-

(a) The deflector inlet is to be preferred for the following reasons:-

(i) Deflector inlet has a substantially higher efficiency than other types especially at slopes above 3 or 4 pc.

(ii) Deflector vanes set at an angle of say 45° do not create any problem of clogging, because they are self-cleaning (Ref. 1).

(iii) Deflector vanes do not introduce any extra inconvenience to traffic, because the top of the vanes is at the same level as the gutter.

(iv) The inlet with deflectors will absorb much higher total flow for zero-bypass than other types of inlet.

The only disadvantage is the extra cost required to fabricate the deflector vanes.

(b) As far as efficiency at "gutter flowing full" conditions is concerned, no benefit would be likely to be gained either by putting a recess in the kerb or by increasing the gutter transition length from 4ft. to 8 ft. This is seen from Figure 11.

(c) For maximising flow with zero-bypass, the kerb-opening inlet with recess in kerb looks more promising than the inlet with transition length increased from 4 feet to 8 feet.

Reference

1. "The Design of Storm-Water Inlets" Department of Sanitary Engineering and Water Resources, The Johns Hopkins University, Baltimore, Maryland, June 1956.

The following work was also consulted:-

R. J. Wasley "Hydrodynamics of Flow into Curb-opening Inlets"; Technical Report No. 6, Department of Civil Engineering, Stanford University, November 1960.

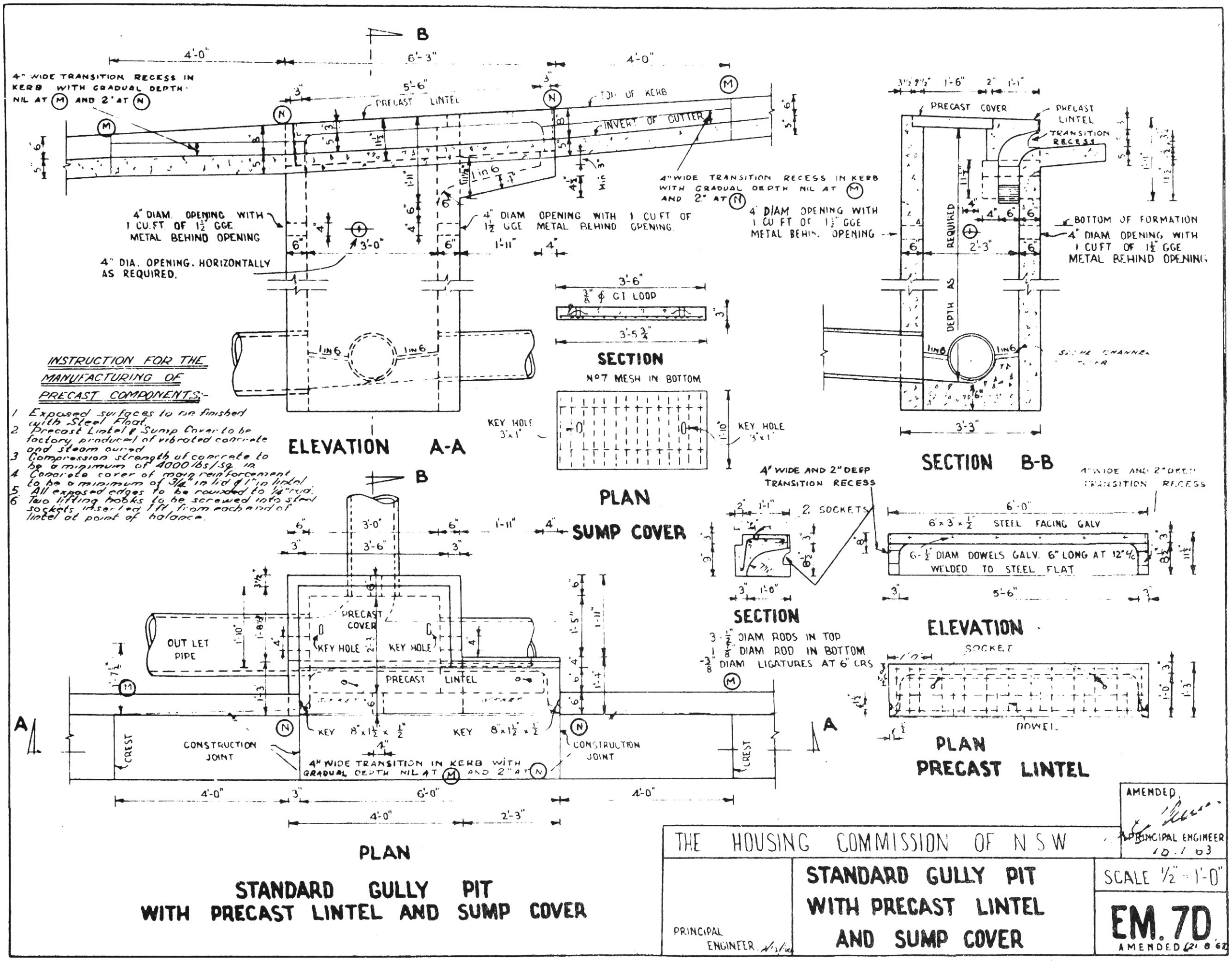

Figure 1: Details of prototype kerb opening inlet. (Reprinted from Housing Commission of N. S. W. Drawing No. EM. 7D).

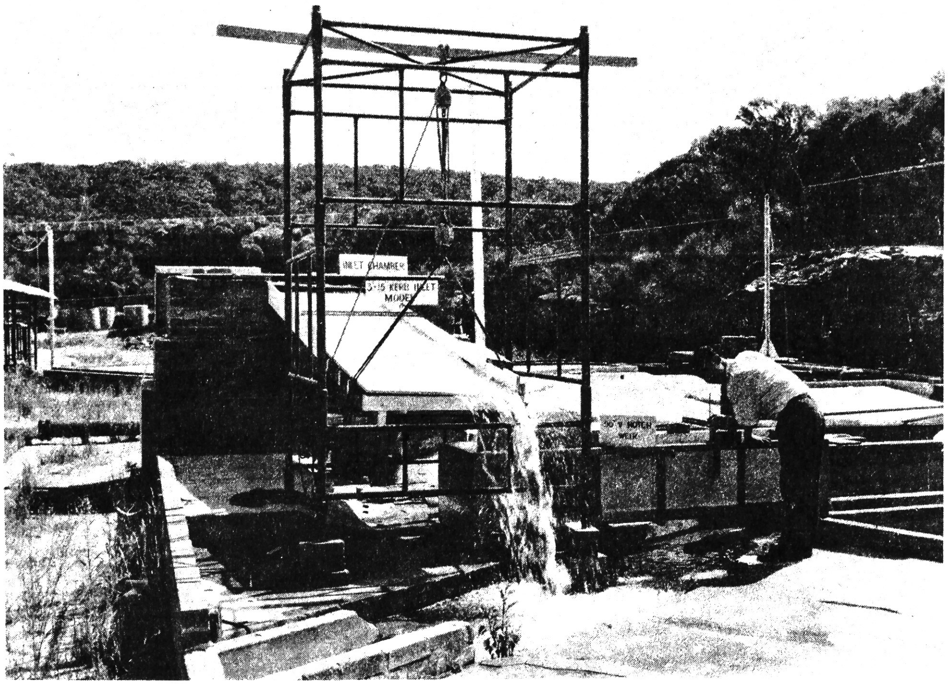

Figure 2: Photograph showing the model under operation.

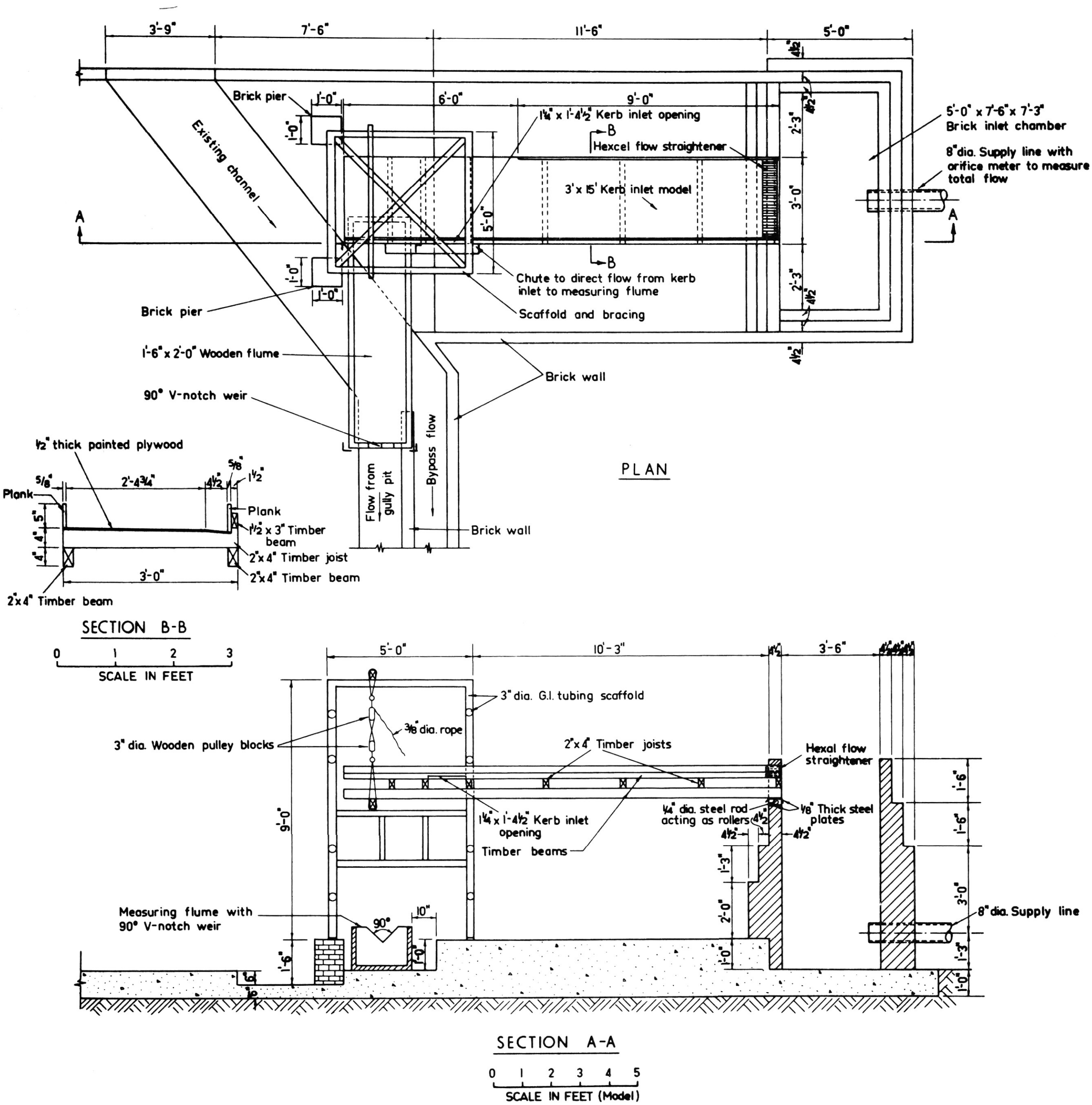

FIGURE 3: GENERAL LAYOUT OF 1:4 SCALE MODEL

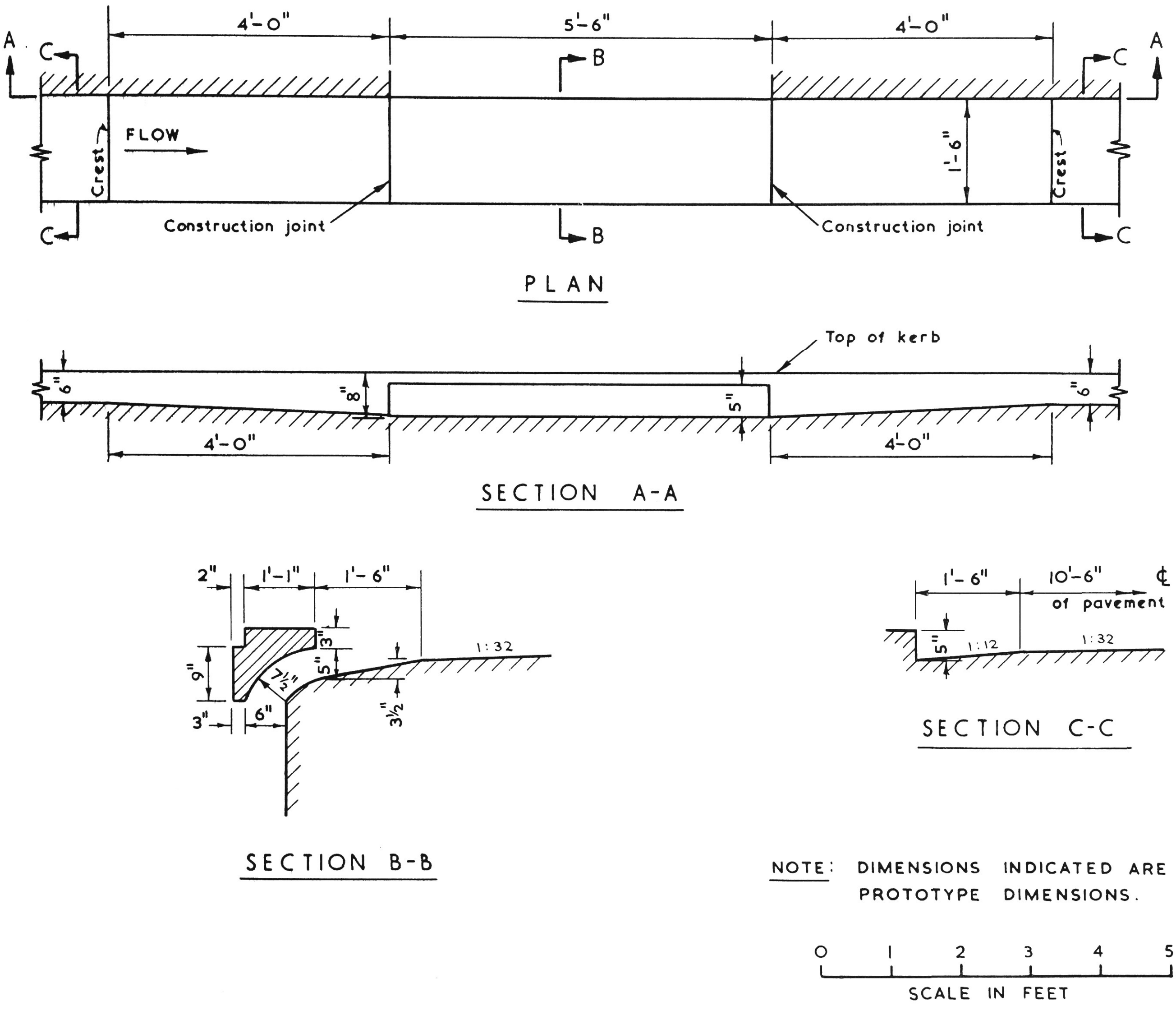

FIGURE 4: KERB-OPENING INLET (Original Housing Commission Design)

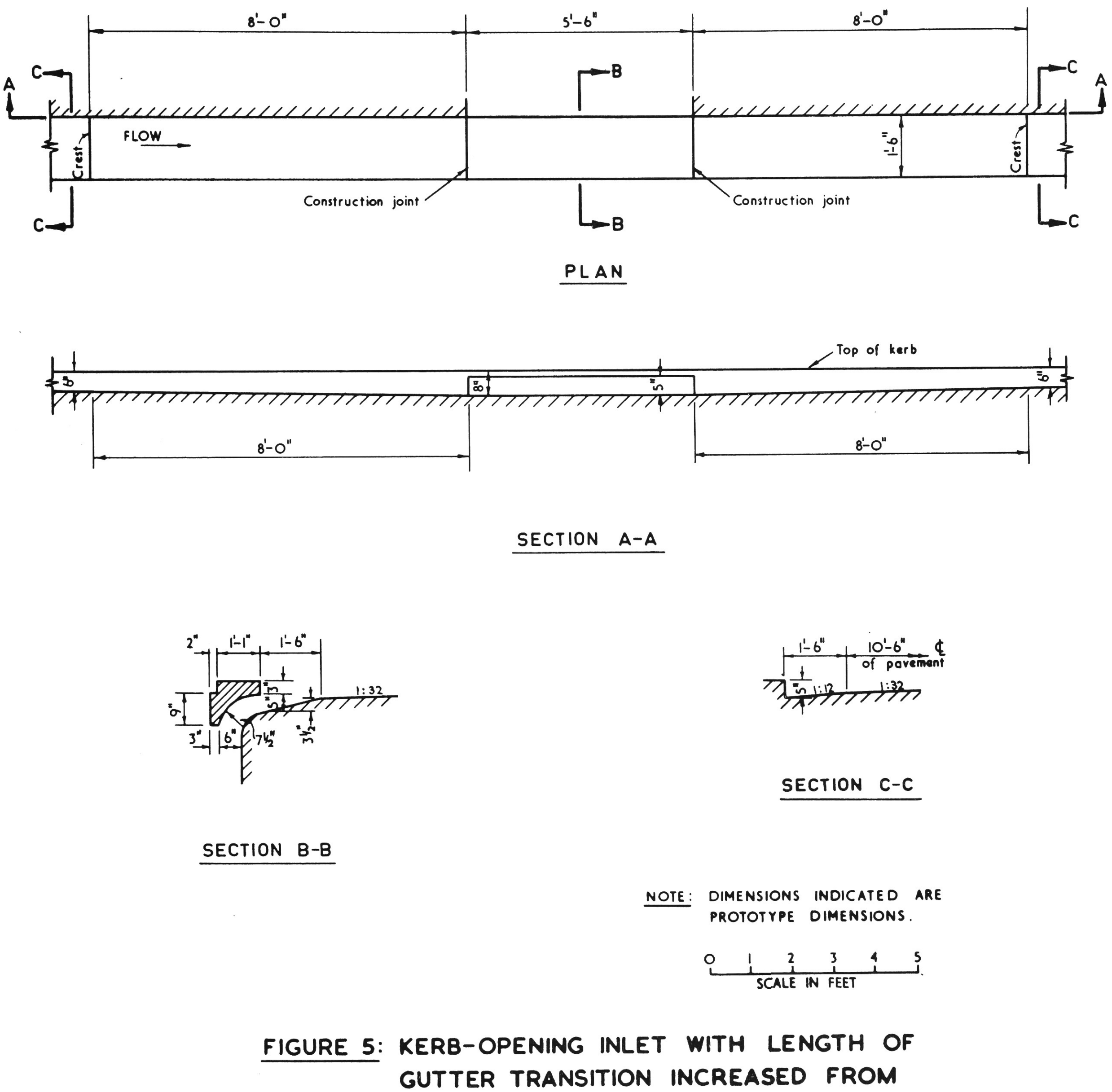

FIGURE 5: KERB-OPENING INLET WITH LENGTH OF GUTTER TRANSITION INCREASED FROM 4 FEET TO 8 FEET

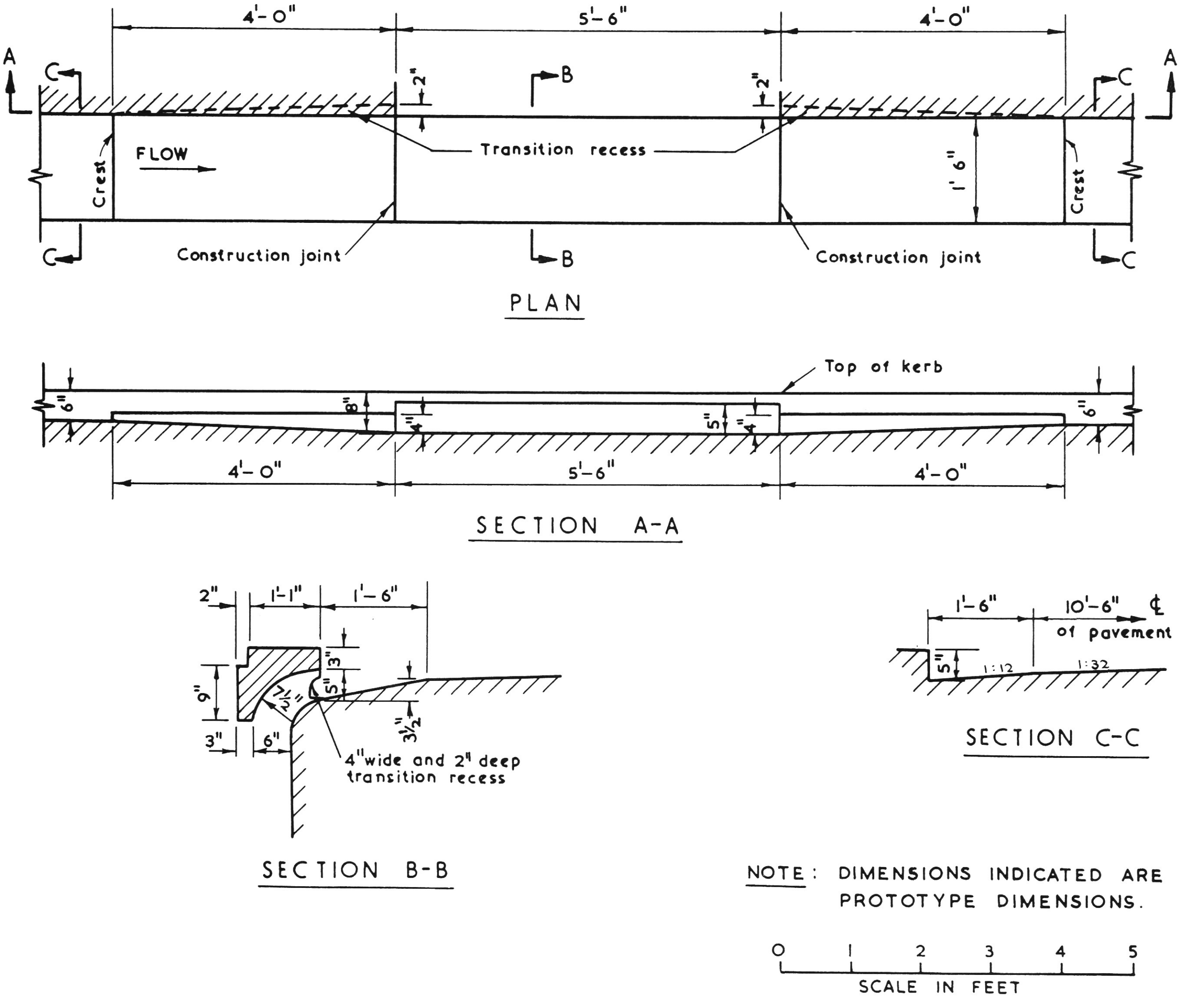

FIGURE 6: KERB-OPENING INLET WITH RECESS IN KERB

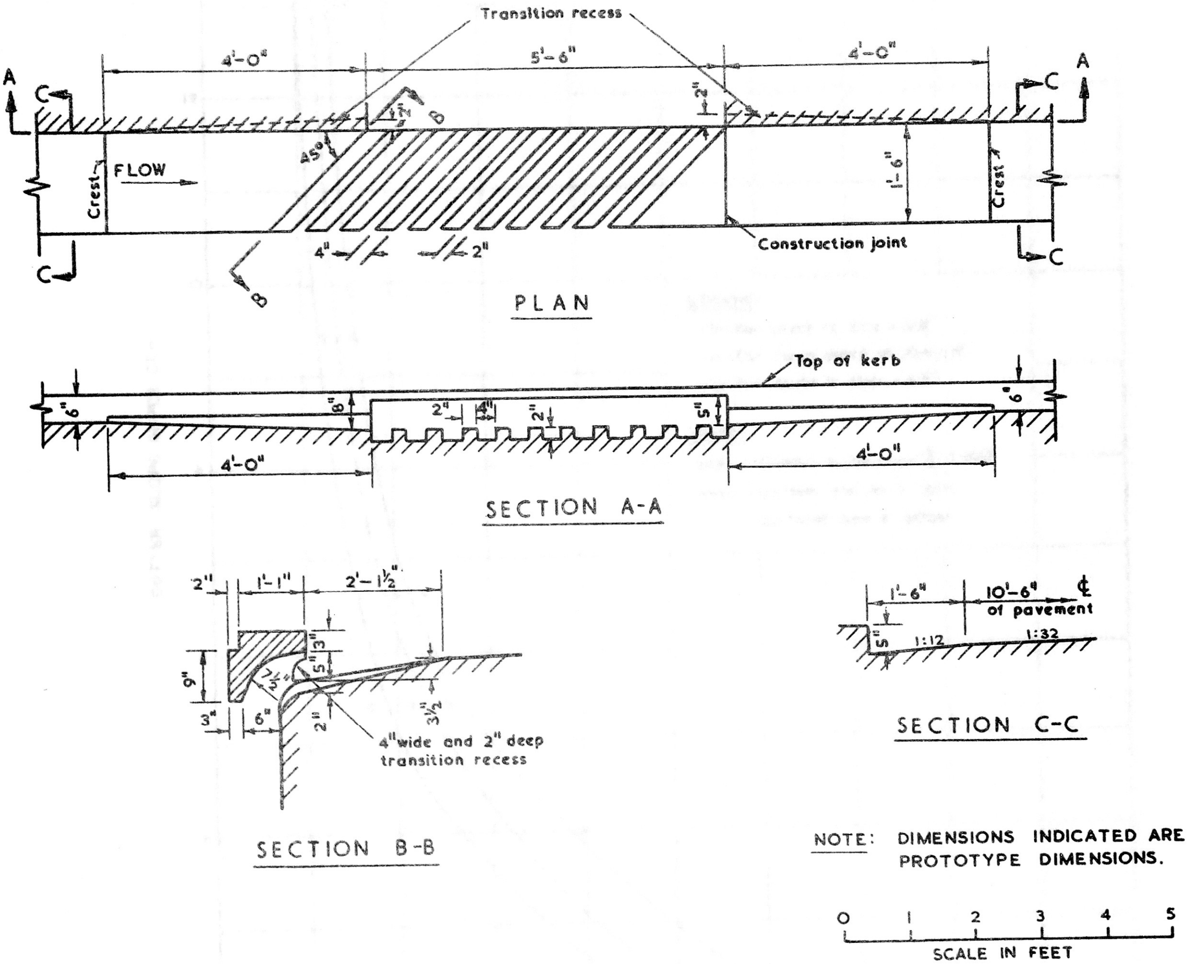

FIGURE 7: KERB-OPENING INLET WITH RECESS IN KERB AND DEFLECTORS IN GUTTER

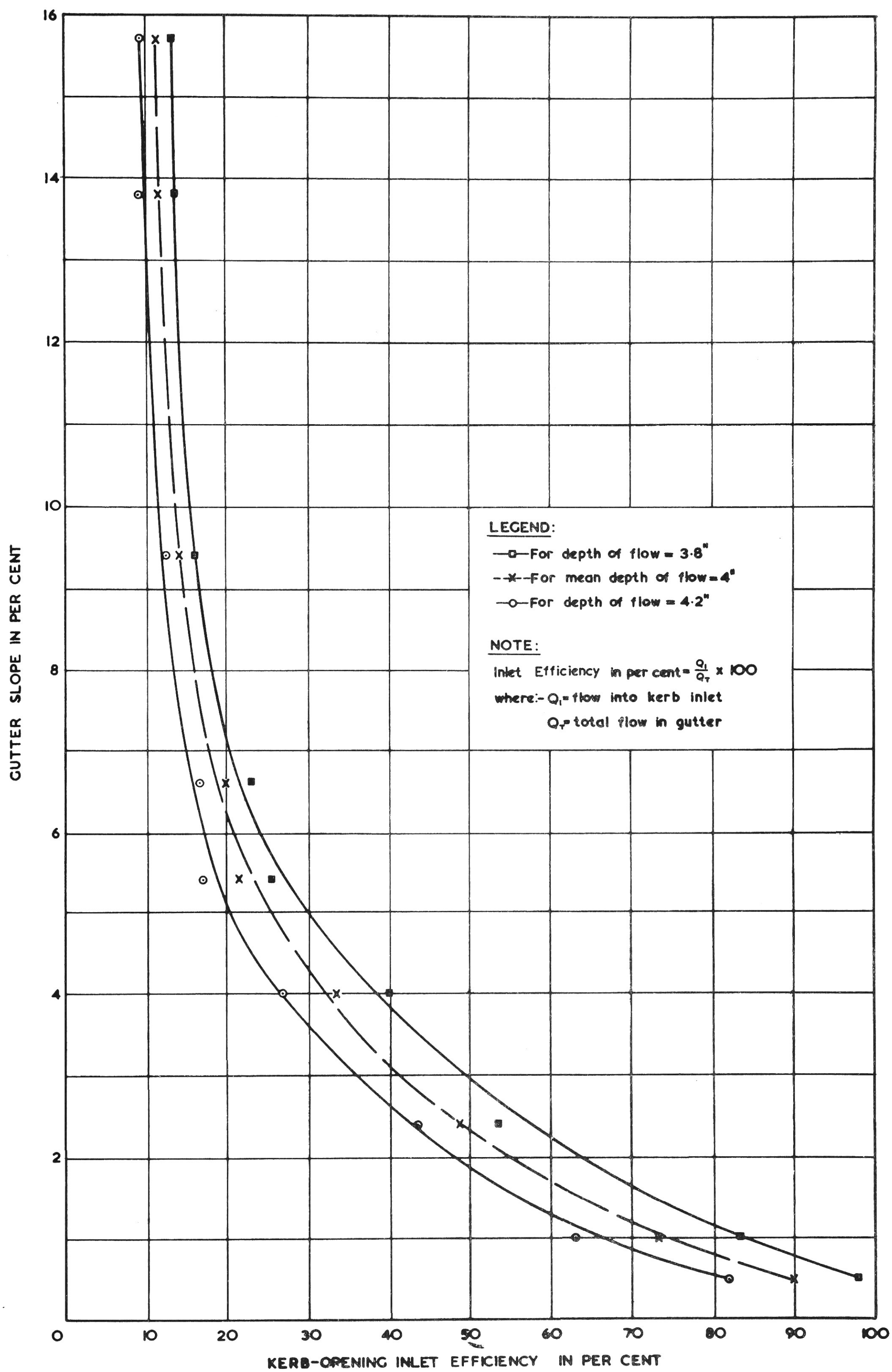

FIGURE 8: VARIATION OF EFFICIENCY OF KERB-OPENING INLET DUE TO VARIATION IN DEPTH OF FLOW

(For Original Housing Commission Design)

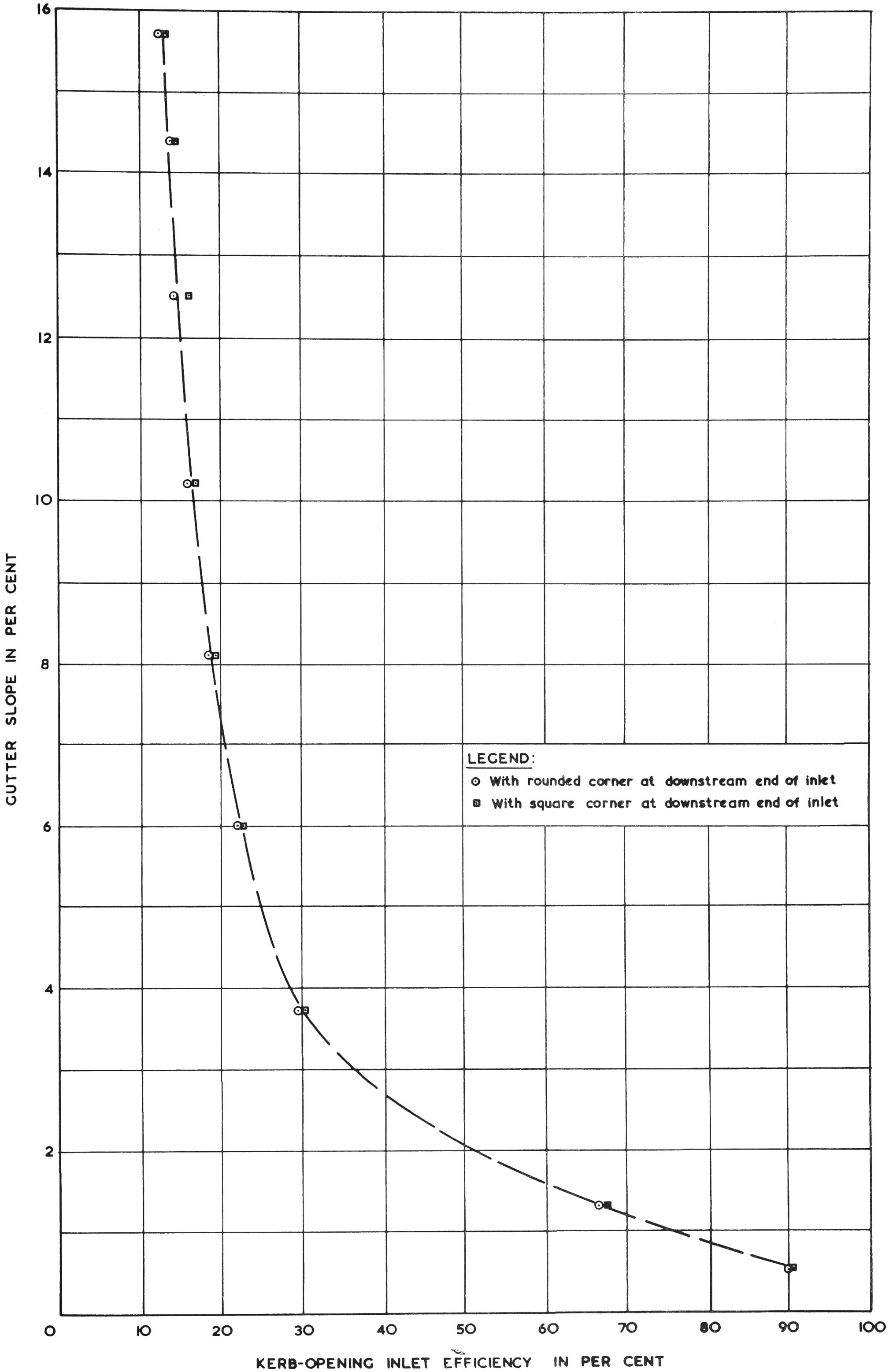

FIGURE 9: COMPARISON OF EFFICIENCY OF KERB-OPENING INLET WITH ROUNDED AND SQUARE CORNER AT DOWNSTREAM END OF THE INLET – FOR 8 FEET TRANSITION LENGTH

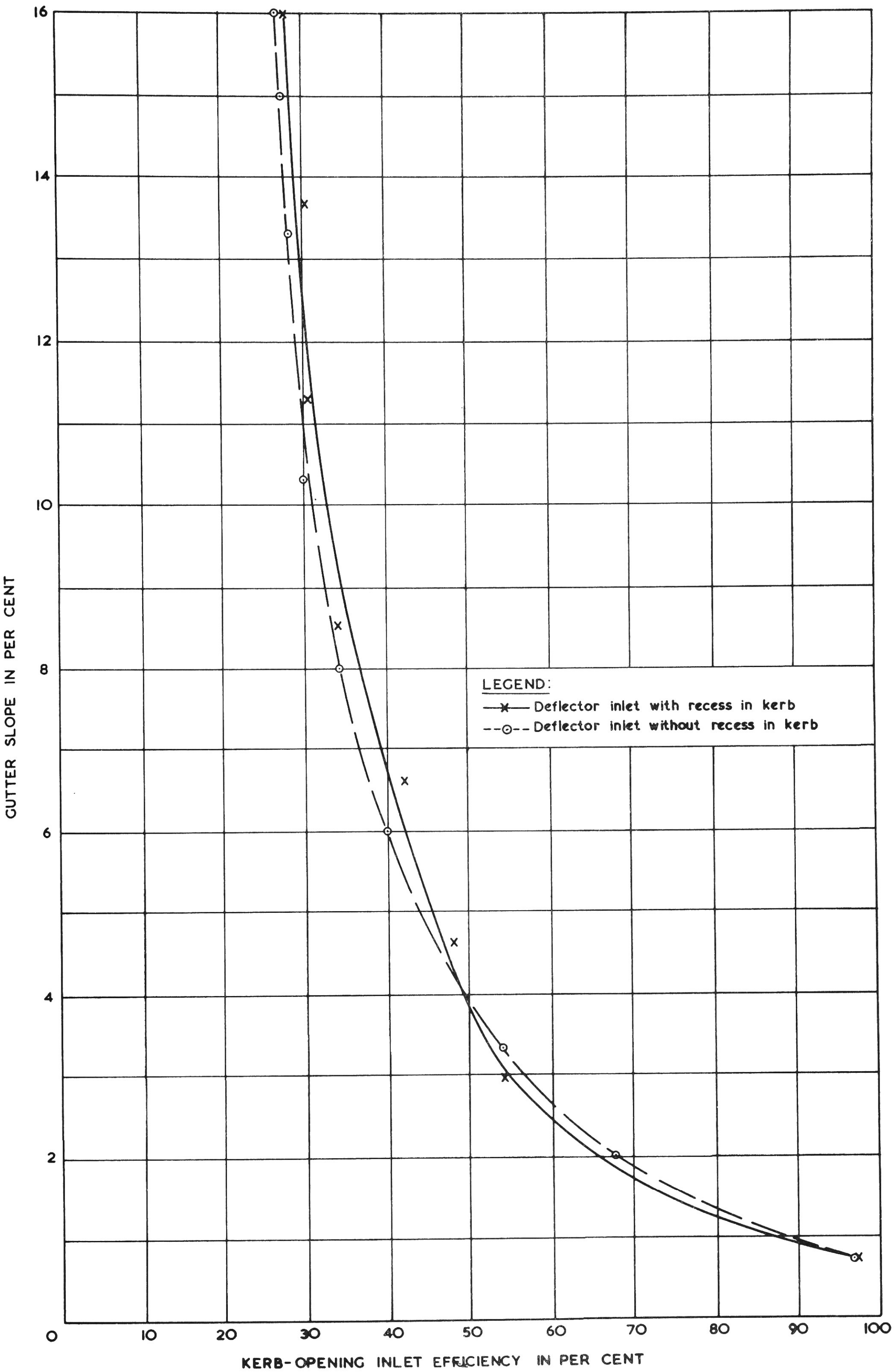

FIGURE 10: COMPARISON OF EFFICIENCY OF DEFLECTOR INLET WITH AND WITHOUT RECESS IN KERB

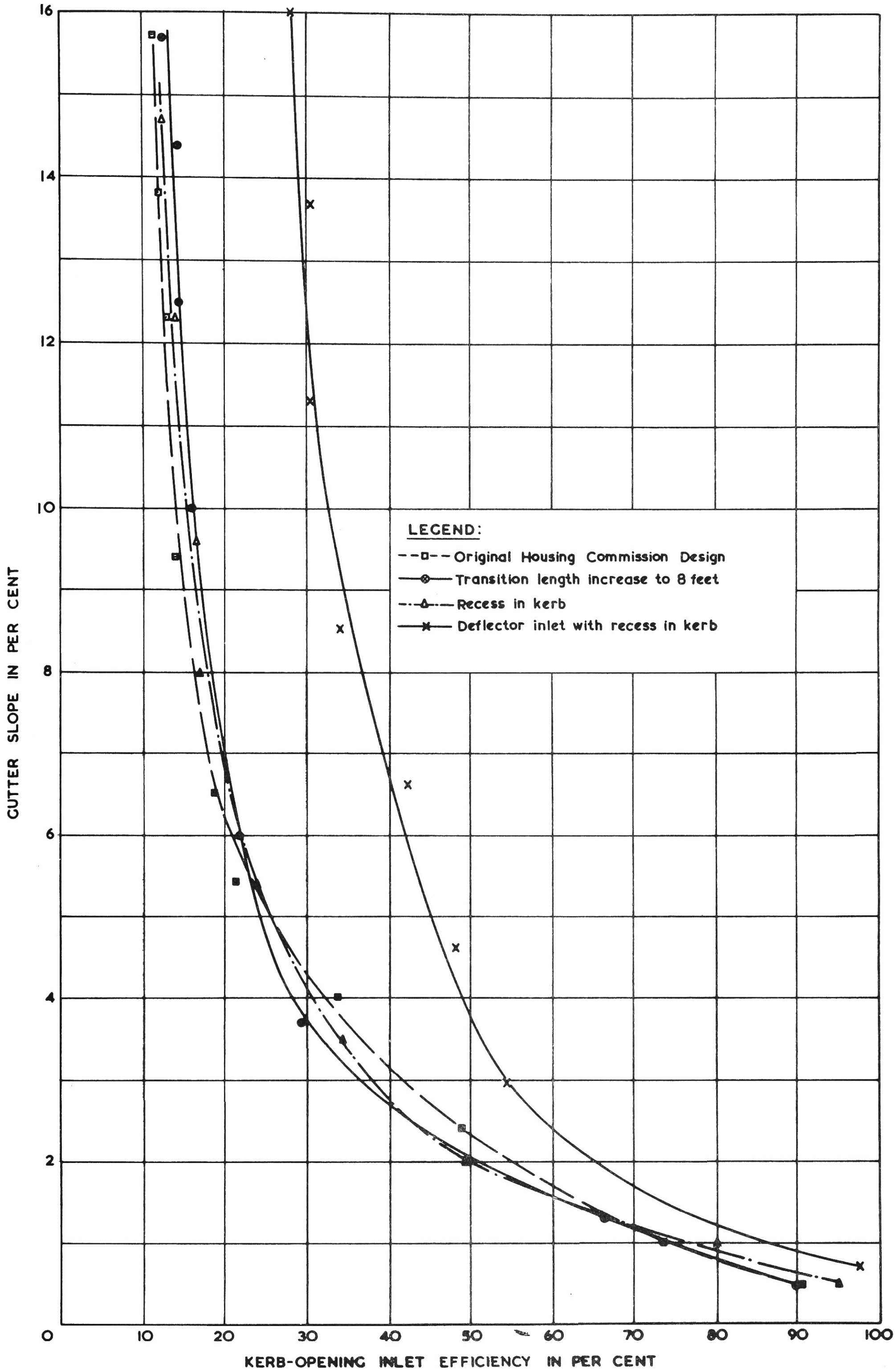

FIGURE 11: EFFICIENCY OF KERB-OPENING INLET FOR ORIGINAL DESIGN AND WITH VARIOUS MODIFICATIONS IN GUTTER AND KERB

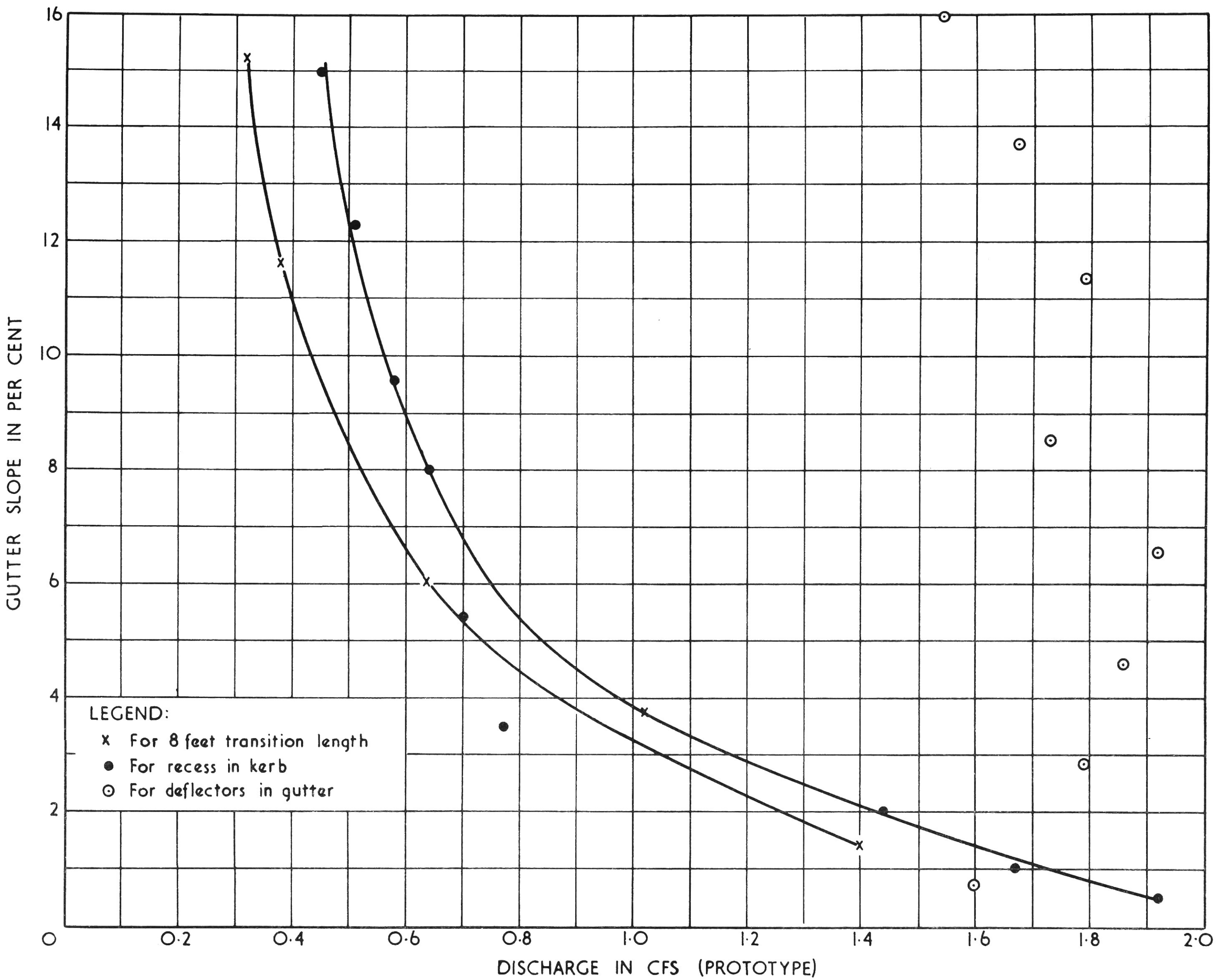

FIGURE 12: RELATIONSHIP BETWEEN GUTTER SLOPE AND MAXIMUM DISCHARGE INTO INLET FOR ZERO-BYPASS

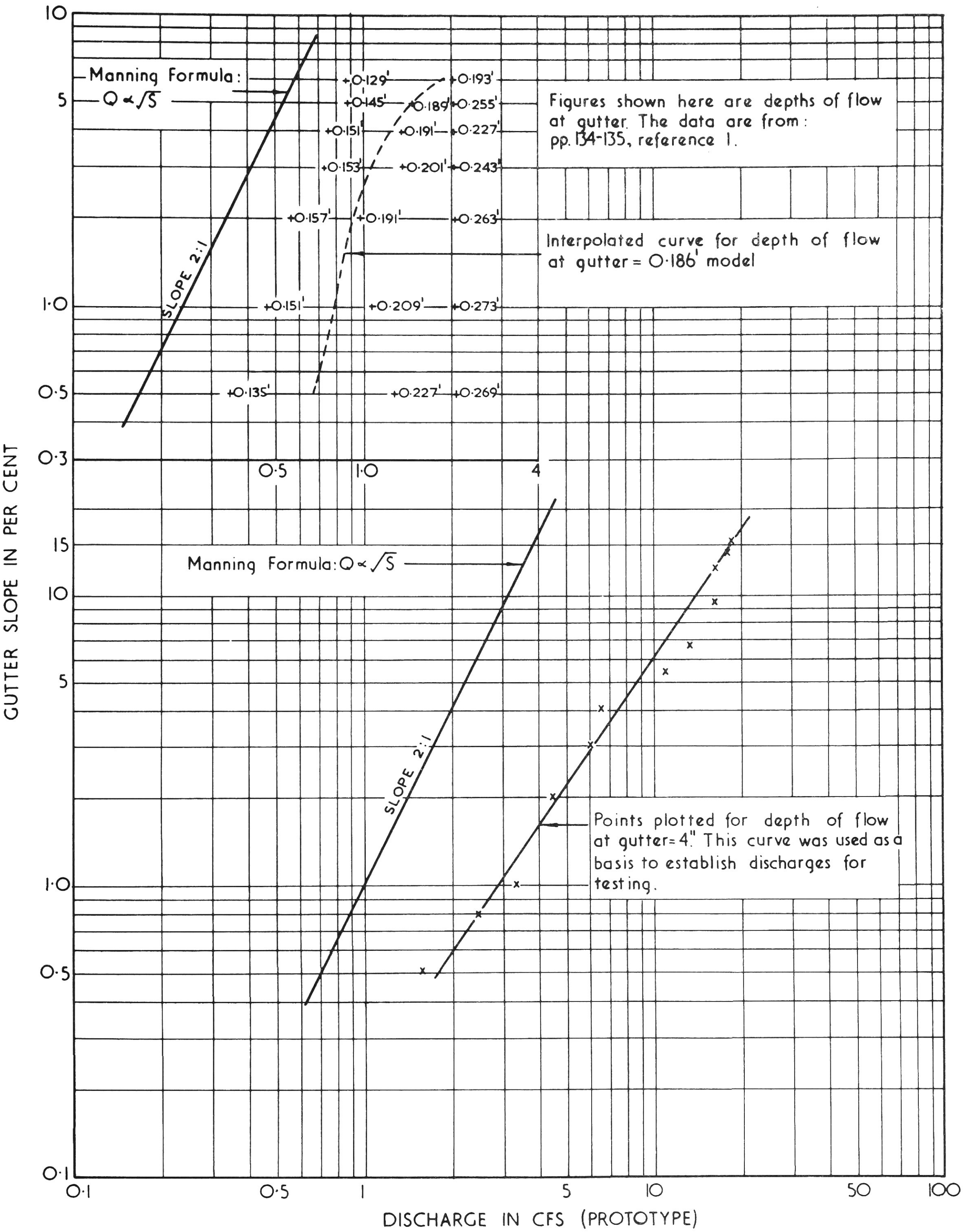

FIGURE 13: DISCREPANCIES BETWEEN MANNING'S FORMULA AND DATA FROM WATER RESEARCH LABORATORY AND BALTIMORE TESTS.