RECOMMENDED DEPTH OF COVER FOR BRIDGE DECK STEEL

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Seventeen New Jersey bridge decks were surveyed by means of a pachometer (nondestructive electronic testing device). The overall standard deviation for depth of cover was found to be approximately $^3/_8$ in. (1.0 cm). Researchers have generally recommended a minimum depth of 2 in. (5.1 cm) to protect the steel from moisture and de-icing salts and thereby reduce the potential for spalling. If all the steel is to be kept below 2 in. (5.1 cm), a specified depth of cover of $3^1/_8$ in. (7.9 cm) is indicated. An operating characteristic curve is presented from which it is possible to determine the necessary specification to protect any selected percentage of steel. The curve indicates, for example, that 90 percent of the steel can be protected with a specification of $2^1/_2$ in. (6.4 cm). Also included are the statistical parameters for individual bridge decks and several basic suggestions to aid in the reduction of spalling distress.

•SPALLING is attributed to corrosion of the top mat of reinforcing steel due to the penetration of water and de-icing salts. The closer the steel is to the surface, the more vulnerable it is to attack. If the current studies to evaluate bridge deck protective systems should prove waterproofing membranes to be the most practical and effective means of protection, depth of cover over the steel will no longer be an important durability factor. However, the results of these long-range studies will not be known for some time and, in the meantime, many bridges will be built without such protection. The purpose of this paper is to determine the appropriate depth of cover to adequately protect the steel in those bridges that are not provided with membranes.

Although the nature of chloride penetration into concrete is such that it is impossible to define a specific depth of cover below which corrosion of the reinforcing steel will not occur, researchers (1, 2, 3) generally agree that 2 in. (5.1 cm) is an effective minimum depth. Given this and knowing the standard deviation for depth of cover, a researcher can determine the appropriate target value to ensure that all (or some specified percentage) of the steel will have the 2 in. (5.1 cm) minimum amount of cover.

The standard deviation for depth of cover was determined from a recent survey of 17 bridge decks in New Jersey. Although the scope of this study was such that it was not feasible to make a true random selection from all bridge decks in the state, an attempt was made to include various shapes, sizes, and methods of construction (hand and machine finished). Because the data are to be used to derive a specification for use with current construction practices, the decks selected were all comparatively new, ranging in age from a few months to about 5 years.

Depth of cover was measured at approximately 40 random locations on each deck by means of a pachometer, an electronic device that nondestructively measures the distance to the top of the steel by means of magnetic flux. The actual bar size must be known in order to interpret the readings accurately. Depth of cover read directly from the dial is accurate enough for many applications [well within $\pm^1/_4$ in. (0.6 cm) when the steel is 2 in. (5.1 cm) below the surface]. Another way is to take numerical readings and determine the depth from calibration curves provided with the instrument. We found a variation of this latter technique to be the most practical for research work.

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We plotted a calibration curve each day the instrument was used because the curve tended to shift slightly as the batteries became weaker.

With our procedure, the standard deviation for repeat readings was determined to be 0.035 in. (0.089 cm). That is, the instrument will repeat within approximately $\pm 1/16$ in. (0.2 cm) 95 percent of the time. Originally, we intended to account for this component of variance in order to separate it from the variability of the steel in the bridges. After the first calculation was made, it became apparent that the instrument error was a negligible component of the overall variance and, thereafter, it was ignored.

Of the 17 decks surveyed, 9 were built with the previous depth of cover specification of $1\frac{1}{2}$ in. (3.8 cm) and 8 were built with the current specification of 2 in. (5.1 cm). Figures 1 and 2 show the data from these 2 groups of bridges. The distributions are approximately normal with means close to the specified depth of cover. The mean for the older bridges is greater than the specified value (i.e., greater depth of cover) by 0.16 in. (0.41 cm); the mean for the newer bridges is less than the specified value by the same amount. Both of these differences are statistically significant, suggesting the existence of an assignable cause.

Basic differences between the 2 groups of bridges may account for this opposite shift of the means, but it is not known which, if any, of these differences was a causative factor. In addition to the difference in the required amount of cover, another major difference is the method of finishing. The older bridges were mostly hand finished, and the newer bridges were predominantly machine finished. As far as we could determine, the steel was secured similarly for all the bridges. A minor change, which occurred at the time the depth of cover specification was changed, was a slight increase in the overall thickness of the deck slab, but it is not known whether this increase in dead load would influence the deflection of the span during the pour in a way that would reduce the cover over the steel. No tolerances on the depth of cover specifications were given, but most of our construction personnel were of the opinion that both specifications were treated as minimums. The data from the earlier bridges (Fig. 1) appear consistent with this belief, and the data from the recent bridges (Fig. 2) do not. The increase in specified depth may have created an attitude on the part of inspectors to the effect that, "if $1\frac{1}{2}$ in. (3.8 cm) was satisfactory before, an occasional value less than 2 in. (5.1 cm) will not matter." Finally, the opposite departures of the means from the specified values may simply reflect the inability of the contractors to control the final location of the steel.

For practical purposes, these differences between the actual values and the expected values of the means are not large enough to prevent the use of the data for the derivation of a useful depth of cover specification. There is no known reason why a contractor would benefit by intentionally setting the steel either slightly low or slightly high. Therefore, the belief is that the departure of the mean from a specified target value will be essentially zero on the average, especially if the specification has equal plus and minus tolerances that are enforced. Therefore, the expected distribution for a new specification will be assumed to be normal with a mean equal to the specified value. The standard deviation for this distribution may be determined either (a) by ignoring the departure of the mean and using the data from the more recent bridges (Fig. 2) as the best estimator of current construction practices or (b) by pooling all the data (coded by subtracting the specified value), which will essentially eliminate the departure of the mean. Both methods produce exactly the same result, a standard deviation of 0.38 in. or approximately $3/8$ in. (1.0 cm).

This value is then used to construct the operating characteristic curve shown in Figure 3. This curve indicates the depth of cover required to keep any selected amount of steel below the 2-in. (5.1-cm) desired depth. For example, if a designer decided to protect 90 percent of the steel, a depth of cover of $2\frac{1}{2}$ in. (6.4 cm) would suffice. If all the steel is to be kept below 2 in. (5.1 cm), a specification of $3\frac{1}{8}$ in. (7.9 cm) is necessary.

Once an appropriate target value has been decided on, a suitable plus or minus tolerance must be added to complete the specification. Ideally, a statistical survey of the level of top steel for several bridge decks just prior to placement of the concrete would determine what degree of accuracy could reasonably be expected. In the absence of such a survey, field experience and engineering judgment must be relied on. Realiz-

Figure 1. Bridge decks built with 1.5-in. (3.8-cm) cover specification.

OVERALL DISTRIBUTION

N = 398
$\bar{X}$ = 1.66" (4.22 cm.)
σ = 0.33" (0.84 cm.)
$\sigma_{\bar{X}}$ = 0.02" (0.05 cm.)

INDIVIDUAL BRIDGE DATA

MEAN (IN.)	MEAN (CM)	STD. DEV. (IN)	STD. DEV. (CM)
1.75	(4.45)	0.19	(0.48)
1.27	(3.22)	0.23	(0.58)
1.31	(3.32)	0.22	(0.56)
1.88	(4.78)	0.24	(0.61)
1.63	(4.14)	0.27	(0.69)
1.79	(4.55)	0.20	(0.51)
1.72	(4.37)	0.25	(0.64)
1.74	(4.42)	0.27	(0.69)
1.87	(4.75)	0.28	(0.71)

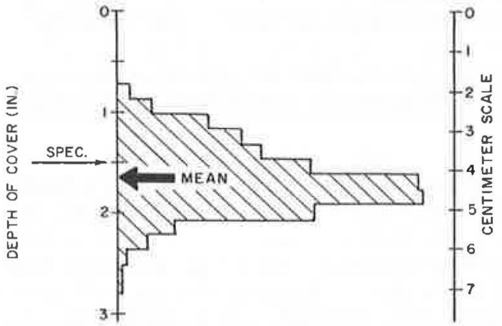


Figure 2. Bridge decks built with 2-in. (5.1-cm) cover specification.

OVERALL DISTRIBUTION

N = 314
$\bar{X}$ = 1.84" (4.67 cm.)
σ = 0.38" (0.96 cm.)
$\sigma_{\bar{X}}$ = 0.02" (0.05 cm.)

INDIVIDUAL BRIDGE DATA

MEAN (IN.)	MEAN (CM.)	STD. DEV. (IN.)	STD. DEV. (CM)
1.88	(4.78)	0.48	(1.22)
2.04	(5.18)	0.37	(0.94)
2.24	(5.69)	0.21	(0.53)
1.60	(4.06)	0.37	(0.94)
1.98	(5.03)	0.24	(0.61)
1.63	(4.14)	0.30	(0.76)
1.65	(4.19)	0.20	(0.51)
1.72	(4.37)	0.18	(0.46)

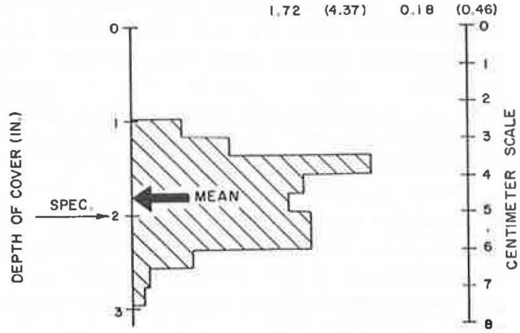
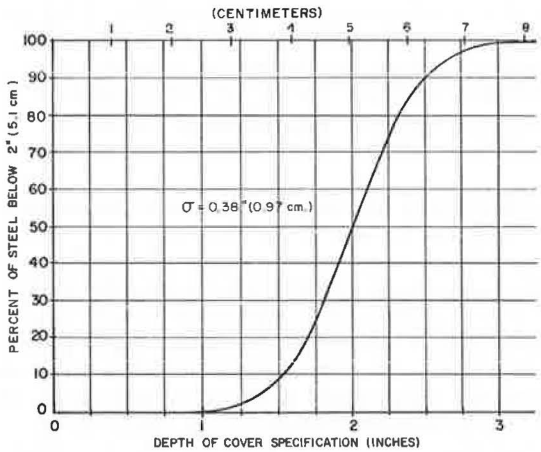


Figure 3. Steel protected at various specified cover depths.



ing that the variability of the steel before the pour would be expected to be less than after the pour and considering the relative ease of correcting steel that is improperly placed, we suggest that ±$^1/_4$ in. (0.6 cm) is a suitable tolerance for the setting of the steel.

SUMMARY AND CONCLUSIONS

1. It is believed that the information obtained from 17 New Jersey bridge decks may be generalized to apply to all bridges within the state and should be a useful guide in other areas where construction conditions and techniques are similar.

2. On an overall basis, depth of cover over bridge deck steel was found to be approximately normally distributed with a mean close to the specified value and a standard deviation of approximately $^3/_8$ in. (1.0 cm).

3. On an individual bridge basis, the standard deviations ranged from approximately $^3/_{16}$ to nearly $^1/_2$ in. (0.5 to 1.3 cm), and the means ranged, both plus and minus, up to $^3/_8$ in. (1.0 cm) from the specified value.

4. A statistically significant difference was found between the older bridges built with the 1$^1/_2$-in. (3.8-cm) specification and the newer bridges built with the 2-in. (5.1-cm) specification. The mean depth for the older bridges was greater than the specified value, and the mean for the newer bridges was less. Although the reason for this is uncertain, these differences were small in comparison to the overall variability and were ignored in order to develop an operating characteristic curve.

5. To adequately protect the top steel [based on the opinion of other researchers that 2 in. (5.1 cm) is an effective minimum depth of cover], a specification of 3 in. (7.6 cm) or more appears to be necessary. If structural designers are reluctant to go that far, other means to improve the situation should be considered, such as (a) provide better (or more frequent) support for the steel to reduce the variability [for example, if the standard deviation could be reduced from $^3/_8$ to $^1/_4$ in. (1.0 to 0.6 cm), the necessary target value to keep all the steel below 2 in. (5.1 cm) in depth would be reduced from 3$^1/_8$ to 2$^3/_4$ in. (7.9 to 7.0 cm)]; (b) require more thorough inspection procedures; and (c) specify a less permeable concrete mix (higher cement factor, lower water-cement ratio) for bridge decks to make it more difficult for water and de-icing salts to penetrate to the steel.

6. Although this study focused primarily on the spalling problem resulting from steel that is too close to the surface, structural designers should take note that it is equally possible for the steel to be deeper than the target value and thereby to reduce the load-carrying capability of the deck. The mean depth of steel for individual bridges (Figs. 1 and 2) was observed to deviate from the specified value by as much as $^3/_8$ in. (1.0 cm). In isolated sections of the deck, it may deviate by amounts greater than this.

7. The pachometer proved to be a handy and accurate instrument for use in collecting a large amount of data in a relatively short period of time. It is also a very useful device for checking a contractor's performance. Readings can be taken as soon as the concrete is hard enough to walk on. It is possible that the steel may be properly set prior to placement of the concrete but that subsequent displacement occurs during the construction operation. If this were found to be the case, appropriate remedial action could be taken for the remaining decks on the job.

REFERENCES

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