Sampling of Concrete in Service

EDWARD A. ABDUN-NUR, Consulting Engineer, Denver

•THE SAMPLING PHASE of the investigation of concrete in service, for the evaluation of its serviceability or the diagnosis of its ills, cannot be separated from the other phases of the overall investigation. This is the case because, in order to sample efficiently, one has to decide what the samples are to be used for and what possible tests or measurements are required to provide the needed information. And, one cannot realistically know these things until after one has developed the history of the particular concrete, assembled all available data that could have a bearing on the end result being sought, and carefully examined the concrete, the site, and the environment in detail. Only after these items have been studied in relationship to one another, and with a tentative plan for the tests that could provide dependable answers, can one develop a realistic sampling plan that will provide the most information for the minimum number of samples at the lowest overall cost consistent with the dependability of the answers to be obtained.

In effect, the investigation of concrete in service requires the systems approach to provide dependable answers at minimum cost. Sampling is only one unit of the system and has to be given its proper place, keeping in mind an overall perspective. This discussion will, however, limit itself to the sampling phase of the system, leaving the remaining facets to be discussed by other authors. It is also limited to concrete in service only. In other words, the discussion is limited to hardened concrete in place in a structure, even though the structure may not have been put to use at the time of sampling.

BASIC PRINCIPLES

What is a sample? A sample may be defined as a unit or portion of a unit that forms part of the universe or population; that is, part of the total structure or portion of the structure or volume of material under consideration. Such a sample is taken as being evidence of the properties, characteristics, or composition of the universe at the particular point or location sampled. A sample taken a few feet away may have different properties, characteristics, or composition, simply because of the inherent variations in materials, workmanship, process, and exposure. Variation is the law of nature, and the closest to uniformity one can come in engineering work is when dealing with a relatively small volume of liquid that is being continuously stirred to keep all portions the same.

One notes in specifications, in various standards, and in test methods a requirement that a representative sample be obtained. Is such a thing possible? In the theoretically uniform liquid described above, a sample taken at any point may be assumed to be representative of the whole. But when it comes to concrete, one soon finds that samples taken from two successive batches differ in their characteristics. On closer observations, one determines that samples taken from two parts of the same batch will also exhibit differing characteristics. When such concrete is placed in a structure, additional variations in placement, consolidation, curing, protection, and exposure tend to increase the original variability of the plastic concrete. This means that it is impossible to obtain a representative sample of a significant volume of concrete or of a significantly large portion of a structure. Therefore, instructions to obtain a representative sample of concrete are unrealistic, to say the least.

All a sample represents is itself and that it is part of the universe or structure or portion of the structure under study or investigation. How then can one take a sample that represents itself only as part of the overall picture and determine what the characteristics of the whole might be? The process is not as difficult as might appear.

Engineers are accustomed to making a series of observations and plotting each observation as a point. After enough points have been plotted, a curve representing the trends of these points can be drawn. The curve can then be expressed in terms of a mathematical equation that accurately reflects the relationships developed by the sum total of the observations.

Each point, representing a pair of observations, represents itself as being a point on the curve or close to the curve, but never representing the whole curve. In the same manner, a series of samples, each representing itself as being part of the larger whole or universe, will provide observations that, taken together and properly analyzed, permit the estimation of the parameters or characteristics of the whole. This is because the variations among the samples (when properly and randomly taken) will reflect the variations of the whole or universe.

To achieve this, with any reasonable degree of reliability or confidence, requires first that the series of samples be taken in a random manner; that is, that the location or time of sampling of any one sample not be determined by the decision or selection of an individual, but rather that such locations be determined strictly by a process of chance not influenced by any individual. Second, it is necessary to take a sufficient number of samples in the series to provide the desired reliability of estimating the characteristics of the parent whole or universe.

SAMPLING PLANS

General Plans

To apply these basic principles to sampling by a producer or contractor for the control of his production or by the owner for determining acceptance characteristics of the product he is buying, it is relatively simple to assume the level of variability either from past experience or from actual records, to decide on the confidence limits or reliability with which one desires to estimate the parameters of the universe or whole, to assume acceptable levels of the producer's risk and the purchaser's risk, and then simply to use the applicable statistical calculations to develop a sampling plan. But the application of this procedure to concrete in service becomes very expensive and, for most purposes, unnecessary. Each sample of concrete in service is more expensive to obtain and test than samples of concrete at the production and placing stages. And sampling plans, developed as previously indicated for control or acceptance, will result in many more samples than needed to solve the problems encountered in investigating the behavior or service record, or to solve a problem regarding distress of concrete in service. If one applies strict statistical procedures, one has not only more expense in sampling, but also unnecessary sampling, thus compounding the costs. Thus, for concrete in service, the selection of a sampling plan in strict compliance with a sound statistical procedure is not practical, either physically or economically.

How can one then adapt these basically sound sampling procedures to the investigation of concrete in service, keep costs within reason, and at the same time have confidence in the results? The first step is to determine the purpose of the sampling. In general, there are two reasons for sampling concrete in service:

1. Sampling to guide control, or to learn the reason a given structure is performing properly and adequately; and
2. Sampling to diagnose trouble or signs of distress, learn what the causes may be, and reconstruct the responsibility.

Sampling a Properly Functioning Structure

Funds for studying a "healthy" structure are rarely available, and when they are, they are very limited. Ostensibly, there are no differences in the outer appearance of the concrete in the structure; otherwise it would immediately be classed in the second category. Here one can simply take the funds available, decide on the tests to be made to provide definitive answers, figure out the cost of taking each sample and testing it, and thus arrive at the number of samples feasible under the circumstances. It is then easy enough to devise a random sampling procedure by dividing the structure into subsections.

Samples can then be taken at points determined at random within each section or random section by the use of random numbers, drawing cards, numbered chips, pieces of paper that have been shuffled in a container, spun in a toy roulette, or whatever the investigator's ingenuity can come up with that will ensure pure chance.

A good example of this type of work was the examination of cores on an Illinois toll highway. In this case, cores were taken regularly on a routine basis for the measurement of thickness of the concrete, which was standard practice to determine thickness acceptability. A core was taken for each 2,000 linear feet of each lane. On a routine basis, a specific fraction of these cores was picked at random and examined petrographically for such things as percent of entrained air and its distribution, aggregate segregation, laitance, carbonation, evidence of bleeding or excessive water content, possible reaction rims on aggregate particles, clay balls, and any other characteristics of interest that could be observed by the petrographer. The purpose was to call attention to any irregularities and to check the effectiveness of the field control, even though there was no evidence of any problem areas that needed to be investigated specifically. This also formed a record to correlate with in case future problems developed, the tested cores being such that they could be related to future distress areas in case these occurred.

Sampling a Poorly Functioning Structure

The "sick" structure seems to be the financially favored child; someone is always willing to supply the funds to find the cause or causes of the trouble, where the responsibility lies, and what to do to repair it. It is always much more expensive and less effective than the other approach, because some damage has already been done that cannot be undone and that remains there as evidence. A reliable sampling plan is more difficult to develop in this case, yet rarely is it practical to apply the full statistical methods developed for control or acceptance purposes.

The first step is to study the records to see if one can pick up any irregularities thay may produce the symptoms on hand. The second step is to examine the structure carefully and mark out the areas or portions in which the symptoms or distress occur in varying degrees of intensity. A numerical scale to describe degrees of distress that has proved useful to the author is as follows:

1. Absent,
2. Faint,
3. Moderate,
4. Marked,
5. Pronounced, or
6. Severe.

But any other scale that serves the purpose of the investigator can be used. If the structure was constructed in two seasons or in cold weather and hot weather, then areas of varying severity of the symptoms should be marked out in each construction unit for which the conditions were reasonably the same to determine if variations in environmental conditions had a significant bearing on the problem.

Once areas have been thus delineated, then it becomes a simple matter of random sampling within each area to provide samples that represent individual points in the structure and that appear to have the same ranges in a variety of characteristics, symptoms, or problems. The number of samples, here again, is a matter of judgment and realism in the expenditure of funds. One can spend justifiably much more money in diagnosing a $100 million structure than in investigating a $100,000 piece of construction.

An example of this kind of sampling is a case where, a few weeks after construction, random overall "boils" or "blisters" that looked like burned spots appeared on the surface of a pavement that had been constructed in winter. The popular reaction of management was that the contractor should not have been permitted to cut reinforcing steel with an acetylene torch while the steel was resting on the concrete. It so happened that there was no steel used in the pavement and none around the project. An examination revealed that these blisters occurred randomly, and the areas could not be separated into areas of varying severity. The typical surface of the blister was raised slightly over the concrete surface, looked whiter than the concrete, and was surrounded by a darker ring where it blended into the concrete that appeared normal. When the blister was tapped, it sounded hollow and the center was friable, whereas the normal-appearing concrete sounded solid, like dense, hard concrete normally sounds. Samples were taken from several of these blisters at random and analyzed chemically. It was found that these blister areas contained calcium chloride in the proportion of approximately 20 percent of the cement.

The specifications had permitted 2 percent calcium chloride in the form of a solution for this winter work. The resident engineer and the contractor had felt that this restriction was just a hindrance to construction progress, so they added the calcium chloride dry. The supply of this salt was apparently badly lumped because of poor storage under moist conditions, and some of the lumps had not broken down in the mixer. These, being lighter than the rest of the mix, had floated to near the surface of the slab. To test this hypothesis, slabs were made in the laboratory, and handfuls of calcium chloride were inserted at different points just below the surface. The slabs were then placed outdoors to weather. Within a few weeks the same blisters appeared. When one arrives at a hypothesis in diagnosing concrete symptoms, one knows he is on the right track if he can duplicate the symptoms experimentally at will.

SAMPLING METHODS

In general there are three methods of taking the actual samples of concrete in service:

1. Coring;
2. Cutting prisms with a diamond saw; and
3. Using nondestructive testing.

Coring is the simplest, quickest, and least costly of all methods of actually taking samples from concrete in service. The breaking of samples by use of a crowbar or sledge hammer is most undesirable, as the process is likely to damage the sample so that one can never be sure that something being observed is a characteristic of the concrete in the structure or was inflicted on it in the sampling. The digging into the concrete to see what is wrong usually destroys the evidence being sought and should never be undertaken.

As a practical matter, a sample may constitute more than one core or piece of concrete so as to provide the necessary quantity of concrete for use in the several tests and analyses that may be contemplated. So far as possible, each test or analysis should be performed on previously untreated and undisturbed concrete, because one test may invalidate the specimen for use in ensuing tests. Where, for some reason, a larger sample than a core is desired, prisms can be cut from slabs by means of diamond saws, and serve the same purpose as cores except for size.

The determination of the proper locations at which nondestructive tests (Schmidt hammer, resistivity, seismic, sonic, etc.) are made is essentially a process of sampling. Such locations should be selected by the same principles outlined for core or prism samples.

SUMMARY AND CONCLUSIONS

This discussion of the sampling of concrete in service may be summarized as follows:

1. There is no such thing as a representative sample of concrete in service. There are only samples that represent individual points.

2. It is neither practical nor economical to utilize the full statistical approaches to reliability, as used in sampling plans for control of quality in production or in acceptance sampling, when one is sampling concrete in service.

3. The most practical approach is to classify the symptoms according to severity of occurrence and take random samples within each such class.

4. A random sampling plan in the various areas of similar symptoms is necessary to provide a series of samples that reflects the variations in the overall total structure.

5. This means that judgment is essential to the success of such investigations. It is not a field for a novice. One must know concrete, construction, design specifications, materials, and foundations, and must have developed skill in relating cause and effect. In other words, one needs experience that develops insights into these interrelationships as a system. In fact, concrete itself is a system within the larger system of the construction of the structure.

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