Non-destructive integrity testing of bored piles by gamma ray scattering

by K. PREISS* and A. CAIsERMAN§

THE POSSIBILITY OF the occurrence of voids or lenses of soil in bored concrete piles and diaphragm walls is a cause of some concern to the civil engineering profession, particularly when the concrete is placed into a bentonite slurry. Several cases of failure as a result of lack of concrete in the foundation have been reported.1-3. The damage suffered to the building owner, to the contractor, and to the insurance companies can in such cases be considerable.

A number of methods of testing bored piles to locate possible faulty zones have been reported. These include core drilling, sonic testing1-3, electrical resistance measurement4, stress wave propagation5 and methods based on neutron or gamma radiation6.

The nuclear radiation test method

The problem of voids or defects in cast piles was first brought to the attention of the authors in 1967. After a survey of the various approaches feasible, it was decided to use a method based on nuclear radiation since that would permit testing of fresh concrete. The three possibilities available with nuclear radiation are neutron or gamma ray backscattering, or gamma ray transmission. These were all investigated6.

Neutron backscattering responds to the volumetric water content of the concrete or void and is therefore very sensitive to a clay inclusion but not particularly responsive to a sand inclusion. Gamma ray transmission which responds to density is often not practical because the distance from source to detector, across a pile diameter, often exceeds 60 cm and therefore requires an intense source with inconvenient safety measures. Gamma ray backscattering provides an instrument responsive to a void, with a weak source, and was chosen as the desirable method.

The equipment developed consists of a probe 48 mm dia and 600 mm long, attached by means of a 30 m long cable to a counting system. To perform a test the probe is lowered into a tube in the foundation and the result registered on a counter or chart.

Fig. 1 shows the probe. The source constantly emits photons, or "particles", of gamma radiation. These photons move in all directions and are scattered or absorbed in the material surrounding the probe. A small fraction of photons happen to scatter into the detector; each detected photon provokes an electronic pulse which is passed up the cable and counted.

The lead plug between source and detector is required so as to shield the detector from radiation emitted directly from the source. As a result, the detector responds only to radiation which has scattered in the medium surrounding the probe.

The intensity of radiation at the detector, which is the detected rate of count in units of counts per second, depends on the mass per unit volume of material surrounding the probe. In the case of concrete in a foundation, a fault that consists of soil and possibly bentonite has a lower density than concrete.

In Fig. 1 is shown the curve of count rate against density for the equipment. In the relevant range of density count rate increases as density decreases. An increase

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in count rate therefore indicates a void. A scatter is observed on the results for a sound foundation, due both to the non-uniformity of real concrete and due to the statistical randomness of the radiation emitted from the source. However, the increase in count rate due to a fault far exceeds the scatter observed in good concrete.

The calibration curve is unaffected by forces of chemical bond in the concrete. Change of density in concrete as it sets is small, and thus the equipment can be used on fresh concrete to locate voids.

The volume “seen” by the probe is approximately 25cm high and 10cm radially into the concrete. The probe therefore tests only the concrete around the test pipe.

The equipment, shown in operation in Fig. 2 was constructed specifically for testing foundations. The radioactive source is weak and does not require any special safety precautions. Furthermore the data is obtained as the test is made. This feature is especially useful when testing fresh concrete as is often done when the responsible engineers wish to have firm information on the quality of the piles as they are placed, or when a contractor wishes to leave the site as soon as placing is completed.

Field tests

The equipment has been used in Israel to check bored piles and diaphragm wall sections since May 1972. During this time it has gained acceptance as a control procedure, and is often employed as a standard test, on a routine basis.

All the tests reported here are from the routine field tests, and not from piles made for research. Although the equipment can be used in bored holes to verify the results of cores, such results are not reported. The results for all the piles tested until December 1974, a total of 1024, were taken from steel pipes which were fixed to the reinforcing cage. Most of the tests were on round piles, but about 80 were diaphragm wall sections. Most piles were poured into bentonite slurry, but shallow piles were often placed dry. No cased piles were tested.

The tests represent a sample with a higher frequency of faults than should be expected for all the piles constructed during the period discussed. Testing included a larger proportion of the more difficult sites, and was usually concentrated at the beginning of the various projects, when faults are more likely than later.

For 90 piles, correlative information was available from coring or from excavating to expose the pile. Since these tests were not performed as part of a research project, the information obtained was not always as detailed as it would be in a tightly-controlled research programme. The cores taken, or the excavation made, were at the initiative of the foundation consultant, the structural designer, or the site engineer, and were required by them in order to make decisions about possible repairs, or to convince the licensing authority about the soundness of the foundations, or to provide further evidence for legal proceedings. The data is therefore from real life situations where time and other pressures are often of greater importance than scientific completeness.

For all the round piles tested, the steel pipes were fixed on the inner side of the reinforcing cage. The number of pipes was determined by the pile diameter. For diameters up to 60cm, two pipes were usually installed, for diameters up to 100cm three pipes and for diameters over 150cm four were generally used. In this way about 25 per cent of the concrete in the pile periphery was tested for the presence of voids.

Data and conclusions from the field tests

Fig. 3 shows a typical result, with a photograph subsequently taken of the fault thus discovered.

Table I shows a summary of the correlative results to date. Of the 90 correlative tests, there was agreement between the gamma ray method and other results in 76 cases. In all cases where a foundation was exposed after registering a fault, the fault was seen. There was no case where the test method missed a fault subsequently located by coring or excavation.

In 14 cases the test method discovered faults not located by coring. The reason for this appears to be that the core tests only the concrete in the bore, which is about 50cm² in section, in the vicinity of the pile.

![Fig. 2. A test in progress](image)

![Fig. 3. A typical result (example 3-C-B7) with the fault subsequently exposed](image)

**Table I—Comparison of Results by the Non-Destructive Gamma Ray Method and from Coring or Exposure**

<table>
<thead>
<tr>
<th>Observation by coring</th>
<th>Sound</th>
<th>Presence of void</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
<td>14</td>
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<tr>
<td></td>
<td>0</td>
<td>11</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Observation by exposure</th>
<th>Sound</th>
<th>Presence of void</th>
</tr>
</thead>
<tbody>
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<td>29</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>20</td>
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<table>
<thead>
<tr>
<th>Total results</th>
<th>Sound</th>
<th>Presence of void</th>
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<tbody>
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<td>14</td>
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<td></td>
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<td>31</td>
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</table>

Total number of foundations compared—90
centre. The gamma ray method tests a larger volume of concrete, about 500cm$^2$ in section, located at the periphery where the probability of a void is higher than at the pile centre. It may be concluded from these results that this non-destructive test is reliable, and more sensitive to voids than cores alone.

The results of the 1024 foundations tested gave an interesting picture of the frequency of voids in such elements. Presentation of these statistics requires clarification as to what constitutes a fault or void, and such a definition may be different for different projects, as the considerations differ from job to job. In order to avoid this pitfall, the results in Table II are presented for several definitions of a fault; the reader is invited to use his engineering judgement in assessing the results. The faults observed are presented in the following classification:

(a) An imperfection, or void, observed at any depth at one or more pipes. This category includes all imperfections, including those with a void seen at only one pipe, that is, at one point on the perimeter. Some 19 per cent of the piles fall into this category. It would be wrong to infer that all 19 per cent were piles incapable of satisfactory structural performance. On the other hand, 81 per cent of the piles showed no imperfection at all, thus indicating that the number of structurally satisfactory piles exceeded 81 per cent.

(b) An imperfection observed at two or more pipes, at any one depth. Such a fault is more serious than type (a) above. If two test tubes are used in a pile, and both show a fault, it may be inferred that the fault includes at least half the perimeter and possibly some of the pile core. If four tubes are used, a fault observed at two tubes or more covers at least a quarter of the pile circumference. The piles in this category, 8 per cent of the total, therefore, reflecting an imperfection is observed over a quarter or more of the circumference.

(c) Lack of concrete at the base of a foundation which would lead to a loss of end-bearing. It should be noted that many of the piles in this category were not considered to be end-bearing piles in the design analyses. Some 8 per cent of piles were in this category.

The results are quoted for three ranges of foundation depth $D$, defined by the limits 12m and 20m. Table II shows the number of foundations of each depth range tested, with the number of projects involved, and gives some picture of the extent of the work reported. The greater incidence of faults in piles of depth between 12m and 20m is not of special significance, since it is due to several sites in one region founded at that depth on a hard uneven layer which gave some difficulty.

The type (b) fault was found in 81 piles (see Table II). Of these, 13 had two faults in one pile, making 94 type (b) faults observed. Fig. 4 shows a histogram of the depths of these faults, with faults observed at the end of the piles shown as a shaded zone. It may be observed that the depths at which faults are observed may be placed in two broad categories: faults at the ends of piles, and faults in the upper 5m, particularly at 3m depth. A fault may of course occur at any depth, but it appears that faults are more likely in the two regions referred to.

Acknowledgements
The tests were carried out, and the results quoted in this article made available, as a result of the enlightened co-operation of a large number of engineers, contractors and owners, to all of whom the authors express their sincere appreciation.

References

Table II—FREQUENCY OF FAULTS

<table>
<thead>
<tr>
<th>Depth $D$ metres</th>
<th>No. of projects</th>
<th>No. of foundations</th>
<th>No faults</th>
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<th>b</th>
<th>c</th>
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<tbody>
<tr>
<td>$12 &lt; D$</td>
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<td>253</td>
<td>36</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>$12 &lt; D \leq 20$</td>
<td>16</td>
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<td>392</td>
<td>118</td>
<td>49</td>
<td>54</td>
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<td>$20 &lt; D$</td>
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<td>225</td>
<td>182</td>
<td>43</td>
<td>18</td>
<td>14</td>
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<tr>
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<td>1024</td>
<td>827</td>
<td>197</td>
<td>81</td>
<td>82</td>
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