SOUND VELOCITIES IN SOME INDIAN ROCK SPECIMENS

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1. INTRODUCTION

The determination of sound velocities and a study of related properties such as the elastic behaviour for rock specimens is of some importance to geologists and physicists. Adams and his collaborators and Bridgman (1931), Zisman (1933), Roess (1935) and a number of others employed static methods for studying the elastic behaviour of rocks. Birch and his collaborators (1936, '38, '39, '40 and 43) and Ide (1935, '36) and a few others studied the same problem by dynamic methods. Application of more recent techniques developed in the field of ultrasonics to such investigations has now been recognised as a fruitful branch of work and Schaefer (1942), Prasadarao (1947) and Bacher (1949) published a few results. Prasadarao's investigations on Indian rocks were of a preliminary nature as they did not include the determination of velocities of transverse ultrasonic waves nor did he correlate his results with certain important geological features such as the granular structure and variations in mineralogical composition from grain to grain in the specimen. Bacher, however, used ultrasonic methods to obtain the velocities of both longitudinal and transverse waves in certain rocks. The ultrasonic technique has, in recent years, been very much improved and it is thought desirable to make a detailed and more complete study, than has hitherto been done, of the specimens of Indian rocks. In this work, the ultrasonic wedge method developed by Bhagavantam and Bhimasenachar (1944) has been employed and over a dozen rock sections studied. In six cases, velocities of transverse waves also have been measured in addition to those of the usual longitudinal ones and some interesting observations made for the first time.

2. DESCRIPTIONS OF ROCK SPECIMENS

A brief description of the various rocks studied in these investigations is given below:
(a) Sedimentary Rocks

Limestone.—The colour is steel black. It is cryptocrystalline, equigranular, and no variation in chemical composition from grain to grain is noticed.

Grey Hyderabad Marble.—This Pakhal marble having a vitreous lustre is white in colour and equigranular. Calcite and other impurities are present in minute quantities.

Pink Rajputana Marble—The fine-grained pink marble has a pearly lustre and is equigranular. No variation in chemical composition is noticed.

Shale.—When welded into a compact rock, argilaceous material is called shale.

(b) Igneous Rocks.

Pink Hyderabad Granite.—The colour is mottled pink, white and black due to felspars and biotite respectively. The texture is inequigranular and variation in chemical composition from grain to grain is seen.

Deccan Trap.—This rock is dark in colour, black to greyish-black on fresh fractured surfaces. The texture is more or less equigranular. Labradorite and Enstatite augite are the essential constituents. There is a uniformity in chemical composition and in structural features as has been pointed out by Krishnan (1949).

Dolerite (Hyderabad).—It is a green rock essentially composed of felspar, chlorite and augite. It is very much altered and inequigranular in texture.

Gneiss.—The crystals of hornblende are linearly arranged. Intercrossed with these bands, there are elongated prisms of zoisite. Quartz is present in abundance. The gneissic texture is clear and the rock is equigranular.

3. Experimental Results

In the following tables are given the results obtained in the present investigation. All the moduli are in units of \(10^{11}\) dynes/cm.\(^2\). In these tables, \(d\) = thickness of section in mm.; \(\rho\) = density in gm./c.c.; \(v_l\) = longitudinal velocity in m./sec.; \(v_t\) = torsional velocity in m./sec.; \(c_{ll}\) = effective longitudinal elastic constant; \(c_{tt}\) = effective torsional elastic constant; \(Y\) = Young's modulus; \(n\) = modulus of rigidity and \(K\) = Bulk modulus.

Tables I and II respresent broadly two classes of rock sections. Figs. (a) and (b) in Pl. XVI show the transmission patterns obtained from limestone (1) and Deccan Trap (3) respectively, both chosen from the group contained
### Table I

<table>
<thead>
<tr>
<th>No.</th>
<th>Rock</th>
<th>$d$</th>
<th>$\rho$</th>
<th>$v_1$</th>
<th>$\ell$</th>
<th>$y$</th>
<th>$\nu$</th>
<th>$K$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limestone (Piduguralla area)</td>
<td>2.57</td>
<td>2.84</td>
<td>6362</td>
<td>3084</td>
<td>11.6</td>
<td>2.7</td>
<td>7.9</td>
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<tr>
<td>2</td>
<td>Limestone (Bhima)</td>
<td>1.52</td>
<td>3.00</td>
<td>6212</td>
<td>3100</td>
<td>11.5</td>
<td>2.9</td>
<td>7.7</td>
</tr>
<tr>
<td>3</td>
<td>Deccan Trap (Gulbarga)</td>
<td>1.95</td>
<td>3.10</td>
<td>6477</td>
<td>4085</td>
<td>13.0</td>
<td>5.2</td>
<td>12.1</td>
</tr>
<tr>
<td>4</td>
<td>Dolerite</td>
<td>3.20</td>
<td>3.10</td>
<td>6463</td>
<td>4096</td>
<td>13.0</td>
<td>5.2</td>
<td>12.1</td>
</tr>
<tr>
<td>5</td>
<td>Hyderabad Marble</td>
<td>1.85</td>
<td>2.88</td>
<td>6832</td>
<td>3811</td>
<td>13.5</td>
<td>4.2</td>
<td>10.7</td>
</tr>
<tr>
<td>6</td>
<td>Rajputana Marble</td>
<td>1.65</td>
<td>2.93</td>
<td>5611</td>
<td>3465</td>
<td>9.2</td>
<td>3.5</td>
<td>8.3</td>
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### Table II

<table>
<thead>
<tr>
<th>No.</th>
<th>Rock</th>
<th>$d$</th>
<th>$\rho$</th>
<th>$v_1$</th>
<th>$\ell$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dolerite</td>
<td>2.52</td>
<td>3.12</td>
<td>5146</td>
<td>8.2</td>
</tr>
<tr>
<td>2</td>
<td>Shale</td>
<td>1.48</td>
<td>3.07</td>
<td>4934</td>
<td>7.5</td>
</tr>
<tr>
<td>3</td>
<td>Granite (pink)</td>
<td>1.90</td>
<td>2.74</td>
<td>6396</td>
<td>11.2</td>
</tr>
<tr>
<td>4</td>
<td>Granite (grey)</td>
<td>1.80</td>
<td>2.82</td>
<td>6407</td>
<td>11.6</td>
</tr>
<tr>
<td>5</td>
<td>Granite (green)</td>
<td>1.91</td>
<td>2.76</td>
<td>7075</td>
<td>13.8</td>
</tr>
<tr>
<td>6</td>
<td>Gneiss</td>
<td>3.35</td>
<td>2.83</td>
<td>6766</td>
<td>13.0</td>
</tr>
</tbody>
</table>

In Table I. Similarly Figs. (c) and (d) are the patterns obtained from pink granite and gneiss chosen from the group in Table II. The comparatively feeble transmission and the consequent presence of only one prominent order of diffraction on either side of the centre in the latter cases is a noteworthy feature of the pictures. Care has been taken to use nearly the same thickness and maintain the same oscillator power in all the above cases. In spite of special efforts, transverse oscillations could not be excited in the group of rocks described in Table II.

In certain cases, where doubts have arisen as to the correctness of the fundamental frequency of the rock section chosen, either by its being too close to one of the natural frequencies of the oscillating crystal or by other inherent difficulties in interpretation when it gets mixed up with the spurious maxima exhibited by the wedge, further work has been done by preparing sections with different thicknesses from the same rock and verifying that the fundamental frequency varies inversely with the thickness.
4. SOME SPECIAL FEATURES OF THE INVESTIGATION

A complete determination of elastic constants in rocks, which are in the nature of polycrystalline aggregates, presents special difficulties. The elastic properties of aggregates are dependent on the randomness of arrangement, closeness of packing, particle size and mineralogical composition of the crystallites on granules composing the aggregates. Some of these aspects have been mentioned by Birch and Bancroft in their earlier work on rocks (1939). If the crystallites are distributed in a perfectly random manner in space, the problem becomes somewhat simpler and the resulting polycrystalline aggregate will be elastically isotropic. It will then exhibit only two elastic constants. For simplicity, rock sections under investigation, are chosen in random direction and since they are generally small, the large-scale structural variations in the rock get eliminated from the problem. Nevertheless the finer or grain to grain variations of size and mineralogical composition continue to be of considerable significance as will be seen later. Mention may be made of one other complication which arises in such studies and that is the presence of minute foreign matter usually occurring in the form of cementing material between various granules.

On account of these special features in the case of rocks, it was found difficult to determine $c_{44}$ which is the torsion constant by the wedge method. This is undoubtedly to be interpreted by saying that in a composite material like a rock it is not so easy to excite torsional waves as in a metal or a crystal plate. Instead of a wedge, quartz plates of other cuts such as AT, BT and Y have also been tried with a view to see if the rock section could be forced to oscillate at places where there is no regular resonance but without success. Finally, after several trials, a Y-cut plate having a thickness of 1.5 mm. and an area, comparatively much smaller than that of the rock section, had to be chosen and cemented to the rock section for the purpose of successfully exciting torsions. In this set-up it was found that the shear modes are excited more prominently than the longitudinal ones. From the transmission maxima, the shear modes are easily sorted out and the corresponding fundamental frequency calculated.

It must be remarked here that if the rock section and the oscillating crystal stuck on the section have comparable dimensions, they have been found to constitute themselves into a composite system and complicated modes are excited, making it difficult to get at any of the natural frequencies of the rock or of the crystal.

5. DISCUSSION OF RESULTS

One outstanding result of the present investigation is that strong ultrasonic patterns showing a large number of diffraction orders are shown by
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one set of rocks (Figs. a and b), whereas the other set shows comparatively feeble transmission (Figs. c and d). Broadly speaking, all the rocks classified in Table I are of the first category and their geological structure is such that there are no violent variations of mineral composition from grain to grain in them. On the other hand, the rocks classified in Table II are characterised by an inequigranular structure. Granites, for instance, contain several types of grains such as quartz, felspar and mica. These differences manifest themselves in sound transmission and enable us to divide them broadly into two classes. In rocks where the structure is markedly inequigranular, sound absorption takes place to a large extent, probably by a process of scattering. In rocks where the granular structure is more uniform and where chemical composition does not vary from grain to grain, it has generally been found that there is a free transmission of ultrasonic waves. Further it has been observed that in the whole group of rocks, given in Table II, it was not possible to excite torsions even with the special methods employed for obtaining them in the group given in Table I. These results suggest that sound transmission depends upon the particle size, the closeness of packing and the variation in chemical or mineralogical composition from grain to grain. Only in rocks, where all these conditions are prevalent in a reasonably uniform manner from place to place, it is possible to get definite and intense sound transmission maxima. A further distinction of interest has been found between rock sections and metal or single crystal plates in that in the former the transmission maxima are generally not sharp as in the case of latter materials.

The author's values for longitudinal velocity and the effective longitudinal elastic constant are in general agreement with those of Prasadarao (1947) who also worked with Indian rocks. In Table III, the values for $v_1$ and $v_t$ obtained in the present investigation are compared with those of Bacher who worked with similar rocks though they belong to a different geological formation in another part of the world. The agreement is fairly good.

**Table III**

<table>
<thead>
<tr>
<th>Observer</th>
<th>Limestone</th>
<th>Marble</th>
<th>Gneiss</th>
<th>Basalt</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$v_1$</td>
<td>$v_t$</td>
<td>$v_1$</td>
<td>$v_t$</td>
</tr>
<tr>
<td>Bacher</td>
<td>8120 3200</td>
<td>6150 3260</td>
<td>7870 3010</td>
<td>5930 3140</td>
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<tr>
<td>Author</td>
<td>6212 3100</td>
<td>6832 3811</td>
<td>6766 4005</td>
<td></td>
</tr>
</tbody>
</table>
6. SUMMARY AND CONCLUSION

The paper gives the elastic moduli and other relevant features obtained from measurements on sound velocities in about a dozen specimens of Indian rocks.

This systematic investigation of the ultrasonic sound velocities (longitudinal and torsional) in various rock sections by the wedge method, has shown that the differences in granular structure and mineralogical composition from grain to grain are reflected in the transmission patterns that are obtained. Typical cases like limestone, consisting of practically the same chemical substance all through the section, give intense ultrasonic patterns with a large number of diffraction orders. In these rocks we are enabled, by special techniques, to determine both longitudinal and torsional velocities. Cases like granite, on the other hand, consisting of a variety of materials like mica, felspar and quartz give weak ultrasonic patterns and appear to scatter the sound to a large extent. Torsions are not easy to excite in these cases.

There is a further point of interest that in these rocks, the transmission maxima are fairly broad unlike what we get in metals and single crystal plates where they are generally sharp.

In conclusion, the author desires to express his grateful thanks to Dr. S. Bhagavantam for providing the necessary facilities for this work in the Physical Laboratories at the Osmania University.

REFERENCES

8. . . Ibid., 1938, 46, 59 and 113.
18. . . Gerlands Beitraege Zur Geophysik, 1933, 39, 408.
Ultrasonic diffraction patterns through Rock Sections