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Meteorological Office

Climatological Services (M.O.3.)

Hydrological Memoranda, No.3.

A compound rain-gauge for assessing some possible errors in point rainfall measurements.

1. Introduction

1.1 During a Meteorological Office Discussion in 1957 [1] it was stated that "the standard exposure of rain-gauges in Britain represents a compromise to avoid the worst effects of excessive catch through in-splashing, and the loss of catch due to wind eddies caused by the gauge". This remark was followed by brief mention of the use which has been made, in experiments, of a more elaborate form of rain-gauge, in which the rim of the instrument is flush with the ground and is surrounded by a brush or grid surface. But "there have been doubts about whether the brush and grid gauges, designed to avoid errors from either in-splashing or wind eddies, are in fact free from in-splashing", a point that was emphasized by Mr. E. Gold, in closing the discussion, with an expression of suspicion "of the underlying idea, which is a tacit assumption in many rain-gauge investigations, that the gauge which catches most rainfall is necessarily the best".

1.2 A suggestion was put forward for testing the validity of these doubts and suspicions "by having a closely-packed group of nine square gauges surrounded by brush and grid. On occasions of negligible wind the separate catches of the nine gauges should show a symmetrical pattern with amounts a in the centre, (a + b) in each side gauge (in-splashing possible along one side), and (a + 2b - c) in each corner gauge (in-splashing possible along two sides, with perhaps a small reduction, c, arising from a corner effect). If the amount for in-splashing, b, is not completely negligible, the installation could be used to test improved devices of the brush and grid type." (See Figure 1).

1.3 It is believed that a compound gauge of this type has not yet been tried out, and in fact that the suggestion has never before been made. This memorandum amplifies the brief outline of the idea put forward in 1957, with some tentative proposals about the construction of the gauge, and for its use in experiments to determine the best way of installing a standard gauge for routine measurements. It is to be expected that these proposals will be modified as a result of experience in making and using the compound gauge.

2. Construction

2.1 The first point about the construction of the instrument is that the compound funnel should be made all in one piece, with all soldered joints throughly water-tight. It is perhaps an attractive idea that both the construction and use of the gauge might be greatly simplified if it could be made with nine separate funnels, fitting snugly in a supporting frame. Experience with ordinary rain-gauges has shown, however, that quite insignificant-looking leaks can have appreciable effects on rainfall readings. As it would be impossible to ensure the uniformity of any such effects with nine separate funnels, the only alternative is to avoid them.

2.2 With any rain-gauge it is desirable to make the area of the collecting funnel as large as practicable. It was shown during the nineteenth century [2] that the 8 in. diameter rain-gauge is slightly superior to the 5 in. diameter gauge, and for many years, in Britain, the larger was widely preferred as a standard. During the last few decades it has gradually become generally accepted that the slight advantage is negligible in relation to the much greater cost of the larger gauge. With the compound gauge now suggested, purely for experimental purposes and not as an instrument for routine use, size must be considered without paying too much attention to cost. If the gauge is too small, then, with certain experimental surfaces surrounding it, in-splashing affecting the central funnel may not be sufficiently avoided, even in calm conditions. Also, the most useful results with rainfall accompanied by appreciable wind will be obtained only if the downwind funnels are not affected by in-splashing from any type of surface whatever. It is suggested that the nine funnels should each be at least 6 in. x 6 in., or 15 cm. x 15 cm., and perhaps even 9 in. x 9 in. is to be preferred, though experience will soon show whether the smaller size is adequate.

2.3 In conjunction with the compound gauge it will be convenient to use ordinary laboratory measuring cylinders, 100 cc. or 1,000 cc., in order to avoid having to make and calibrate special measuring glasses. With the area of each funnel 250 sq.cm. (side of square 15.81 cm. or 6.225 in.), 100 cc. will represent 4 mm. of rain, and a pint collecting bottle will hold about 0.9 in. With the area of each funnel 500 sq. cm. (side of square 22.36 cm. or 8.803 in.) 100 cc. will represent 2 mm. of rain and a quart collecting bottle will hold about 0.9 in.

2.4 Figures 2, 3 and 4 are based on the smaller of these two sizes and give a fair idea of the proportions of the complete instrument with approximately one pint collecting bottles, and of the complete installation in a pit 7 ft. 6 in. square and 1 ft. deep. The pit would be covered by rectangular panels flush with the ground in order to surround the gauge with various experimental surfaces up to a width of 3 ft. (less a fraction of an inch) all round. In Figure 2a the vertical walls of the compound funnel are shown sharpened to the conventional "knife-edge" rim, but symmetrically, not as in the ordinary gauge, where the edge is asymmetrical, with the inner wall vertical right to the rim. This sharpening of the rim should certainly be attempted, to make the compound funnel as accurate as possible, and to improve direct comparisons with a standard gauge, but it is doubtful whether a blunt rectangular edge to the vertical walls would adversely affect the readings to any serious degree. Figure 2 also suggests how the bottles should fit into the base of the gauge so that replacement of the funnel, with the nine delivery tubes entering the bottles, would be simplified.

2.5 Discussion of the panelling arrangement indicated in Figure 3 is taken up in paragraph 3.6 in the discussion of the use of the compound gauge. It would be an advantage to have the base of the pit of Figure 4 covered with gravel or granite chips, with drainage to a sump filled with loose rubble, as the simplest procedure for reading the gauge would be to remove the surrounding panels along one side and walk on the floor of the pit. The alternative of throwing a plank across the pit to protect the panels from trampling would probably be more troublesome. The panels could be adequately supported by four twin diagonal beams, approaching 5 ft. long, resting on supporting legs in the pit. (Figures 3 and 4). For beams constructed of timber, a 2 in. x 1 in. section should be adequate. The upper surface of the beams should be 3 to 4 in. below the ground surface, so that a panel of this vertical thickness may be supported flush with the ground; panels of smaller vertical thickness would need short legs on their under-sides, perhaps fitting into holes bored in the supporting beams, so that they would also rest on the beams flush with the ground.

3. <u>Use of the compound gauge; level ground.</u>

3.1 The standard exposure of rain-gauges in Britain is on level ground, even in hilly country. As also stated in the Discussion referred to in paragraph 1.1, this standard "definitely introduces a bias in the sampling of rainfall in hilly country", and there are outstanding problems in this connection which could be tackled, at least in part, by an adaption of the compound rain-gauge described. Some of these are mentioned in section 4 below. The first experiments with the compound gauge should be on level sites covering a range of exposures from the conventionally acceptable (a sheltered site which is not oversheltered by objects very near to the gauge) to a fully exposed site on the crest of a ridge.

3.2 In addition to the compound gauge the equipment on each experimental site should include the following instruments:-

3.2.1 A standard rain-gauge exposed with the rim at the standard height of 1ft. above level close-cropped turf. In the course of the experiments, after a satisfactory series of comparisons with this gauge, the immediate surroundings could be varied by having loose gravel for about 1ft. all round the base of the gauge.

3.2.2 A similar standard rain-gauge surrounded by a standard turf wall. This instrument could be omitted in the first experiments on a conventionally acceptable site, and included later only if the standard exposure proved to be poor in moderate to strong winds. Instead of or in addition to the turf wall gauge, gauges equipped with various types of rain-gauge shield could be used.

3.2.3 A cup-counter anemometer. Two such instruments, one exposed at the height of the standard rain-gauge rim and the other at a second height, say 6 ft. or 2 m., should perhaps be used in the first experiments. If it becomes clear either that readings at one height show some definite advantage over readings at the other, or that one instrument alone is quite as useful as two, in all circumstances, the use of a second instrument could be discontinued.

3.2.4 A wind vane.

3.3 There is little doubt that frequent observations, irregularly spaced in order to take account of individual falls of rain, and determined by a continuous watch on the weather, would yield more precise information than a programme of regularly spaced observations, determined in advance without regard to the sequence of weather. However, for the application of the results to the main body of rainfall data, available now or in the future, such information might be too precise, and not worth the greater effort which would be necessary to collect it. There is much to be said for collecting data, with the experimental equipment, based very largely on the conventional rainfall day, that is on observations only once a day at 09h. G.M.T. Short periods of more intensive observations might be superimposed on the basic programme, if it seemed that by this means particular problems which arose could be clarified.

3.4 The first experiments with the compound rain-gauge would be carried out with the surrounding pit covered by panels of wood or other material with a hard smooth surface, in order to produce, deliberately, something approaching the maximum possible degree of in-splashing. The objects of these preliminary experiments would be:-

3.4.1 To verify that with rainfall during a calm, or sufficiently light winds, rainfall readings approximating closely to the symmetrical pattern of Figure 1 can be obtained.

3.4.2 To determine the lower limit of wind speed above which the symmetrical pattern of figure 1 is no longer clearly recognisable. For daily rainfall amounts the limit would refer to mean daily wind speeds, or daily run of the wind, and it could not be expected to have a clearly defined value because of the variations of rainfall and accompanying wind speeds which occur in any period as long as 24 hours.

3.4.3 To discover whether, at wind speeds above the limit of paragraph 3.4.2, there occur definite though asymmetrical patterns, related to wind direction, which appear with sufficient regularity to be used as standards of comparison in later experiments. For the purpose of this object the orientation of the compound gauge indicated in Figure 3 would be convenient.

3.5 The second set of experiments would naturally be governed by the success achieved in the first set. Assuming that the first two objects can be satisfactorily attained, even if the lower limit of paragraph 3.4.2 proves to be very small, the second set would be carried out by covering the whole of the pit with panels of one kind, using a surface intended to reduce in-splashing; and then using, in succession, a number of different types of surface either wholly artificial or designed to simulate some more or less natural surrounding for the gauge. The surfaces might include:- brushes with vertical bristles set in a perforated base (bristles of different lengths, possibly up to 3 in. long); bristle door-mat; woven matting; wire mesh of various kinds; egg-crate or honeycomb grids (various sizes); natural or simulated short grass; gravel or granite chips (the panels being shallow perforated trays); etc. Simple laboratory trials with an arrangement for spraying various surfaces, might aid the preliminary choice, but would not in themselves be sufficient without field tests. From a sufficiently long series of experiments it should be possible to place the various surfaces in an order of effectiveness with regard to in-splashing, and to determine whether the best surface discovered eliminates in-splashing entirely. This conclusion would be valid with either of the following results:-

3.5.1 If the catches from the nine funnels are identical, over a range of intensities and wind speeds, within acceptable limits of accuracy of measurement (perhaps as low as 0.01 in.).

3.5.2 If the catches from the nine funnels, though not identical within acceptable limits of accuracy of measurement, vary from the mean catch for any occasion by amounts which are randomly distributed, according to satisfactory tests, with regard to both the position of the funnels relative to wind direction and to the time sequence of any data series. The condition implies that the percentage deviations from the means for the cumulative sums of a series of catches must tend to zero, for each of the nine funnels, for all wind directions taken separately or together.

If either of these results can be obtained, then and only then it will be possible to state that the validity of the rain-gauge readings has been established, to a degree which has not yet been achieved in any known rain-gauge experiments. At this stage, if it is reached, another ordinary rain-gauge should be set up on the experimental site, in a pit, surrounded in a similar way with the non-splashing experimental surface, to verify that the ordinary rain-gauge, so exposed, will provide a tenth set of readings which can be included with the other nine without upsetting the appropriate test of paragraph 3.5.1 or 3.5.2.

3.6 The third set of experiments could not be seriously considered without a very high degree of success in the second. The object would be to determine, in relation to wind speed, the minimum width round the gauge of the most suitable non-splashing surface. For this purpose the panelling arrangement indicated in Figure 3 would be appropriate. The non-splashing surface would be used for one or more sets of the smaller inner panels, over a width s, the remaining outer and larger panels being made with a smooth hard surface to maximize splashing. With observations over a series of occasions, with different wind speeds and directions, the data would be examined for evidence of in-splashing into the windward funnels, with the object of finding a limiting value of the wind speed, v, below which such evidence could not be traced. Even with observations taken over short intervals, it is unlikely that the limit would be sharp and precise over a large number of occasions, since variation of drop-size distribution and intensity would have the effect of producing a diffuse limiting zone. With daily rainfall amounts and daily run of the wind as the data, a broad diffuse limiting zone is to be expected and a fairly long series of observations would probably be necessary to determine the lower edge of this zone. When this had been achieved for one value of s, the series of trials would be repeated for other values, so that an empirical relationship between s and v, based on at least four or five points, could be obtained. The minimum width of the non-splashing surface required on any level rain-gauge site could then be estimated from any adequate assessment of the wind regime at that site. For an ordinary rain-gauge in a pit, rim flush with the ground and surrounded by the non-splashing surface covering the pit, the possibility of an eccentric arrangement might arise for some sites.

4. Use of the compound gauge; sloping ground

4.1 The use of any type of rain-gauge on sloping ground raises problems which are quite distinct from those concerned purely with the accuracy of rainfall measurement. These relate to the definition or specification of the quantity, the measurement of which is to be attempted. It has been argued that meteorologically, rainfall should always be defined by reference to the amounts passing through a horizontal surface [3], and hence measured by means of a funnel with a horizontal rim, without regard to the slope of the surrounding surface on which the rain falls. Hydrologically, on the other hand, it is important in many circumstances, if not all, to have some knowledge of the amounts which are intercepted by sloping surfaces, of varying aspect with regard to wind direction. This knowledge cannot be obtained in any simple way from measurements with conventional rain-gauges with horizontal rims, because of the complexity which arises from varying wind speeds and directions, and the different angles of approach to a sloping surface of rain-drops of different sizes. Hydrological measurements of rainfall should therefore include the use of some gauges which have funnels with sloping rims. The meteorological definition has the great advantage that a fairly small number of sampling points will provide information about the rainfall over an area. The hydrological definition undoubtedly requires a much larger number of sampling points for adequate information about areal rainfall in hilly country, and is complicated by a further difficult problem, namely the question whether the slope of the rain-gauge rim should correspond strictly to the local slope of the rain-gauge site, or to the average slope over a wider area; and if the latter, over precisely how large a surrounding area should the slope be averaged. If the former, the number of sampling points required would assume enormous proportions, and it seems that, in practice, compromise solutions would have to be attempted. In the early stages of tackling the problem, at least, sites could be chosen so that the strictly local slope corresponded in each case with the average slope over a large area. But it must be recognized that by using this method alone, it would not be possible to provide complete sampling cover for a very irregular area.

4.2 It is not the object of this memorandum to discuss these matters fully. It is assumed that in hilly country measurements may be required on both level and sloping sites, that measurements on level ground, whether natural or artificially created as a rain-gauge site, can be covered, as in flat country, by the suggestions of section 3 above, and that measurements on sloping ground must include both sites which are exposed and sites which are sheltered, with regard to the prevailing rain-bearing winds. It is probably safe to assume, further, that when the wind blows along a slope, that is, not up or down it, the relationships investigated on level ground would apply equally well. Having first carried out experiments on level ground it should therefore be unnecessary to use a compound rain-gauge with nine funnels on a slope, since a set of three funnels along the line of greatest slope should suffice. The suggested arrangement is shown in Figures 5 and 6. The distance s, perpendicular to the line of greatest slope, would be determined from investigations on level ground, and from an assessment of the wind regime at the sloping site, having regard to the orientation of the triple gauge; the ideal distance s would not necessarily be the same on both sides of the gauge. The extent of the panel-covered pit at the two ends of the gauge, up-slope and down-slope, should probably be appreciably greater than s to begin with. On the one hand rain splashing down the slope will travel a greater distance for a given wind speed; on the other, there will usually be greater exposure, on a sloping site, to winds blowing up the slope. Until these counteracting effects have been investigated, it is hardly possible to estimate which is likely to be dominant in any given situation, and in which sense an asymmetrical arrangement of the pit, up and down the slope, is likely to be required.

4.3 The experiments on sloping ground would correspond with the third set of experiments on level ground (paragraph 3.6), the non-splashing surface for the panels having first been discovered. They would be simpler, in that attention would be concentrated on up-slope and down-slope effects, but slightly more complicated in that asymmetry is to be expected, and that in a complete investigation one aim should be to obtain a satisfactory relation between the degree of asymmetry and the angle of slope. There is no useful purpose to be served in pursuing the topic speculatively, however, before sufficient experience has been gained on level sites to enable the investigations to be carried to this stage. The important point is that the use of this type of compound gauge for experimental purposes should lead to the development of a standard gauge, with either a horizontal or a sloping rim, flush with the ground and surrounded by a practically non-splash surface, which could be placed on any site whatever in hilly country. By developments of this kind and probably only in this way the present bias in the sampling of rainfall in hilly country (whether for meteorological or hydrological purposes) could be eliminated.

5. Conclusion

Whilst no attempt has been made to consider the many problems which arise in the attempted measurement of different forms of precipitation - dew, fog deposition, the finer forms of drizzle, hoar frost, rime, snow and hail, - it is suggested that the ideas outlined present what is perhaps the only possibility of obtaining a verified measurement of rainfall proper. Such a measurement could be accepted not merely as a standard, reproducible measurement for comparative purposes, but also as a close approximation to an absolute, against which other standards could be checked. As far as is known, such a self-verifying multiple measurement with a compound gauge has not yet been made.

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M.O.3b
August, 1958
ES.

References

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2. Mill, H. R. The development of rainfall measurement in the last forty years. Brit. Rainf. 1900, London, 1901, p.23.

3. Serra, L. Interprétation des mesures pluviométriques: Lois de la pluviosité. U.G.G.I., Ass. Int. Hydrol. Sc., Ass. Gen., Brussels 1951, 3, Publ. No. 34(1952) p.9.

6. Addendum

Discussion of the draft of this memorandum has shown there is room for doubt about some of the underlying ideas or assumptions, and that such doubts could be cleared up with a few further notes. The implications of paragraph 1.3. are however, strongly emphasized; the memorandum is put forward only as a tentative outline of ideas which will certainly be modified as a result of experience.

6.1. Leaks (paragraph 2.1). The subject of rain-gauge leaks in general is a complicated one. The implication of this paragraph was not that nine separate funnels would in themselves be more subject to leaks than a one-piece compound funnel, but that there would very probably be uncontrollable leaks between the adjoining vertical sides of separate funnels, no matter how snugly they appeared to fit together. It would be impossible to prevent this form of leakage without having a "roof" (a strip of inverted V cross-section) over each of the twelve edges along which any two funnels would adjoin (see Figure 1). The use of such a leak guard would be extremely troublesome. It may be found in practice that the compound funnel can be most easily constructed from nine separate funnels, but it is argued that in that case they must all be soldered securely together to form a single piece with completely water-tight joints.

6.2. Capacity (paragraphs 2.3 and 2.4). It has been pointed out that it is not uncommon for 0.9 in. of rain in one day to be exceeded. In Britain this should not occur on the average more than about three times a year, except in the wetter areas (mainly upland districts). To reduce the average frequency of overflow, and loss of data, to once a year (over most of the lowland districts of Britain), the capacity of the bottles would have to be increased by about 40 per cent. For preliminary experiments in a fairly dry area the additional capacity is hardly necessary, since the information required can be obtained even if an occasional day's record is lost. For later experiments, especially in upland districts, larger capacities would be useful, and a greater depth of the lower part of the compound gauge, to accommodate larger bottles, is suggested. This would be a relatively simple matter to arrange, since the same compound funnel could be used with a deeper base.

6.3. Funnel to funnel splash. The possibility of this source of error was neglected in the memorandum. With the funnel dimensions shown, which include vertical sides of more than $4\frac{1}{2}$ in., it is likely to be completely negligible in most falls of rain, compared with the major effect under investigation. During very intense thunderstorm rainfall, and of course during hail, it will very probably not be negligible. Deliberately ignoring the special problem of the measurement of hail, it is suggested that the data for the most intense falls should be treated with some suspicion, unless there has been an opportunity to watch the gauge on such occasions for any evidence of splashing out of the funnels. If this proves to be a source of appreciable error it will be necessary to modify the dimensions of the funnels.

6.4. Panel supports and panelling (paragraph 2.5.) It has been suggested the the entire pit surrounding the compound rain-gauge could be filled with gravel, to within a few inches of the surface, with the panels round the gauge supported directly on the level surface of the gravel. This might be satisfactory, but for some types of panel suggested in paragraph 3.5, in particular wire-mesh and egg-crate or honey-comb grid, it would be necessary to demonstrate that there was no splashing back through the panels. The gravel or similar material would certainly need to be coarse and rough, with very free drainage through it. It is necessary to emphasize the implication of paragraph 2.5 that walking on the panels should be avoided. As some of the panels, in the arrangement shown in Figure 3, would certainly be heavy, it would perhaps be desirable, or even necessary, to arrange on one side of the pit an access path which could be opened up by removing small detachable sections of the panels. Sections of about 1 ft. square would perhaps be easily manageable.

6.5. Run-off. The possibility of run-off from the panels reaching the outer funnels of the compound gauge was neglected in the memorandum. If it is arranged for the rim of the compound gauge to project a fraction of an inch above the level of the panels, and if there is a gap of a fraction of an inch between the rim of the gauge and the nearest panel, run-off into the outer funnels should not occur. Experience will show how large these "fractions of an inch" must be; obviously they should be kept as small as possible whilst large enough to achieve their object. The possibility of run-off from some types of panels draws attention to the fact that appreciable amounts of water may stream down the outside of the gauge. It is for this reason that in Figure 2 the compound funnel is shown fitting over the vertical walls of the base, with an overlap of a few inches, and not fitting into the base.

6.6 Further notes will be added as necessary, until it is possible to revise this memorandum completely on the basis of experience.

$(a+2b-c)$	$(a+b)$	$(a+2b-c)$
$(a+b)$	a	$(a+b)$
$(a+2b-c)$	$(a+b)$	$(a+2b-c)$

Figure 1

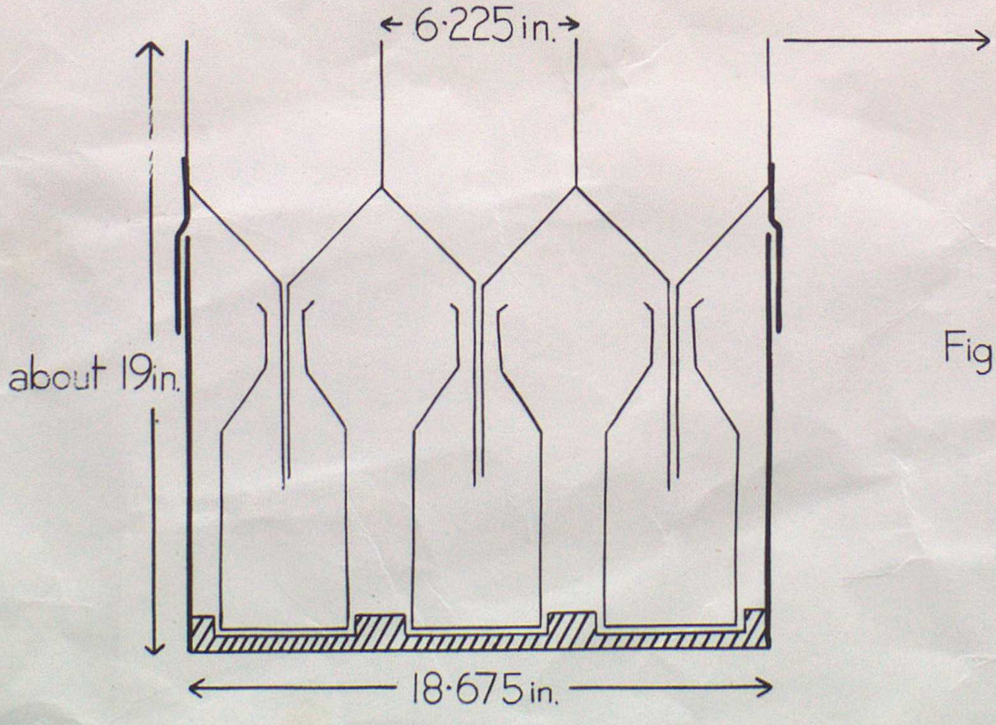

Figure 2

Figure 2a

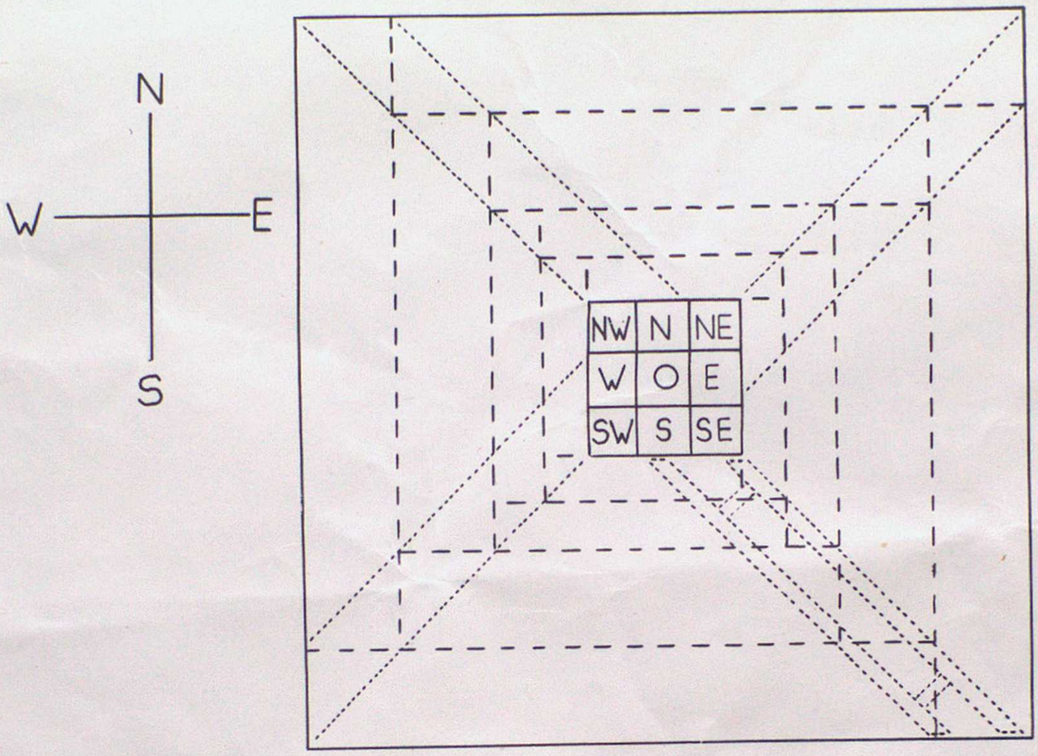

Figure 3

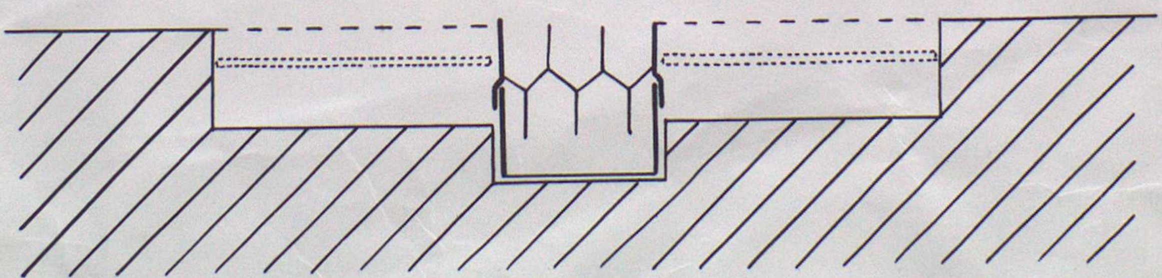

Figure 4

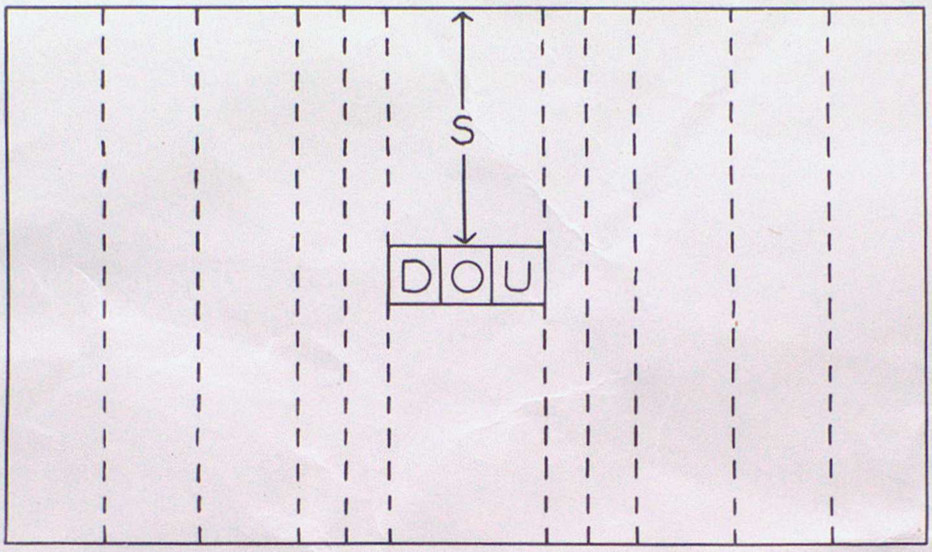

Figure 5

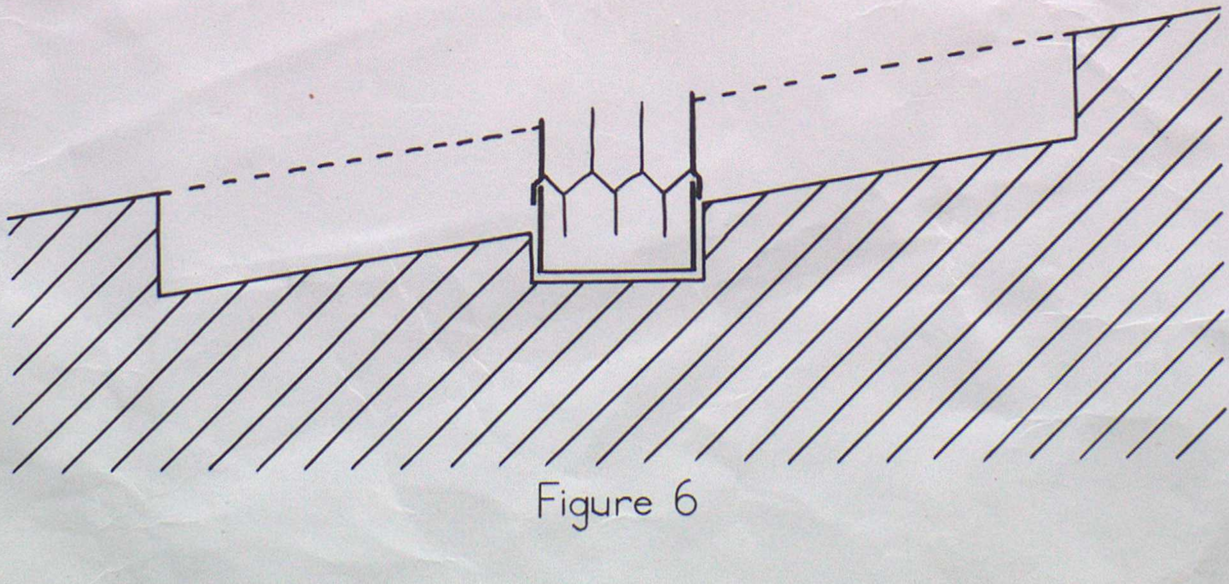

Figure 6