These few examples seem sufficient to indicate that the possibility of suiting pavement design to subgrade condition presents attractive economic aspects

A COMPARISON OF ROAD CONDITIONS WITH ATTERBERG'S LIMITS AND THE OTHER STANDARD SOIL TESTS

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It is desirable, as soon as sufficient data have been collected, to correlate them with the actual conditions upon the highways and determine whether limits may be set upon the various tests indicating where the line shall be drawn between good and unsafe soils

It is also desirable to compare the various soil tests made, for the purpose of selecting those tests which will classify the soil in the safest and most definite manner

In August, 1926, the Co-operative Soil Laboratory at Columbus, Ohio, began testing soils by the Atterberg method, with a view to substituting this method of testing soils for the standards previously used by the soil laboratory of the U S Bureau of Public Roads, which standards were also used by the Ohio laboratory, providing, of course, that the Atterberg tests proved better Therefore the present comparisons have been made

Appended at the end of this report is a brief statement regarding the condition of the pavement at a number of the stations where these soils were taken

In Table I the test data for sixty soils are grouped according to the lower plastic limit and the other test data are given for comparison Opposite and *before* the number of the soil from those stations at which the pavements have shown the most trouble is placed an x Most of the soils whose analyses are shown in this table were selected because they were considered to be bad soils The fact that no x appears before the number does not mean the soil is a good one, but simply that nothing is known about road conditions at that point, or, that the road has not shown failure up to the present This may be due to the road being new, or to light traffic, or to the fact that the road is only an earth road

It will be noted that the roads known to be in bad condition are rather evenly scattered throughout the list with perhaps a slightly greater number near the middle of the list

Comparing the lower plastic limit with the other tests there are a few soils in every one of the test series that do not fall in the same

TABLE I

SOILS ARRANGED IN ORDER OF THEIR LOWER PLASTIC LIMIT

Soil No	Lower plastic limit	Lower liquid limit	Atterberg number	Moisture equivalent	Volumetric change	Susp clay	Total clay
x 60	14 0	17 6	3 6	12 2	15 4	3 7	63 8
220	14 2	22 8	8 6	13 5	13 1	0 5	25 7
32	14 7	21 9	7 2	17 7	12 4	7 2	71 0
x128	14 8	26 4	11 6	18 9	13 9	2 3	48 3
x 57	15 0	29 8	14 8	20 5	21 2	3 9	47 8
139	15 2	24 0	8 8	20 0	13 8	4 5	49 7
x 16	15 5	29 9	14 4	19 2	18 9	2 9	48 8
59	16 2	27 9	11 7	19 6	15 7	5 5	43 7
127	16 3	29 3	13 0	21 2	20 9	9 3	42 9
79	16 3	30 1	13 8	23 6	17 7		
76	16 3	23 5	7 2	15 6	16 5	3 5	40 0
75	16 4	29 0	12 6	18 6	17 5	3 0	50 7
81	16 6	23 4	6 8	16 6	13 3	1 2	33 8
x 15	16 7	33 8	17 1	21 3	17 7	8 6	52 3
85	16 7	34 5	17 8	22 1	21 7	5 5	52 4
x 72	16 7	32 2	15 5	20 4	21 2	6 7	56 9
x 60x	17 0	27 4	10 4	21 3	14 8	6 8	43 6
71	17 0	29 7	12 7	21 6	15 8	4 1	58 5
83	17 1	27 0	9 9	19 6	17 0	2 9	50 8
86	17 1	30 8	13 7	20 6	20 1	4 7	47 5
168	17 3	28 4	11 1	16 8	18 5	2 9	48 3
34	17 4	30 0	12 6	25 4	13 8	7 4	59 9
150	17 6	29 2	11 6	21 0	15 4	11 1	57 5
x 63	17 8	39 6	21 8	25 7	28 1	13 7	59 5
11	17 8	29 1	11 3	21 8	17 4	4 6	65 1
x119	18 0	36 3	18 3	21 6	22 8	6 3	60 9
61	18 0	32 8	14 8	26 2	20 8	8 0	63 7
x 74	18 2	28 6	10 4	17 9	15 3	4 9	39 3
21x	15 4	21 2	5 8	15 5	9 3	2 8	28 4
66y	18 5	31 1	12 6	23 0	21 3	10 0	65 0
25	18 3	28 8	10 5	18 0	12 5	2 8	57 7
x 29	18 5	45 2	26 7	25 5	25 7	3 8	82 0
x 31	18 5	38 5	20 0	23 2	26 1	3 3	73 3
x 15x	18 6	23 8	5 2	20 7	10 5	3 3	47 5
17y	19 8	32 7	12 9	16 5	11 9	1 7	51 4
120	18 7	34 9	16 2	24 3	24 6	6 7	69 4
140	18 8	33 0	14 2	24 3	19 1	8 7	58 3
x 33	18 8	42 0	23 2	27 6	24 0	6 6	70 6
148	19 4	30 1	10 7	24 0	16 3	8 1	53 1
103	19 4	39 6	20 2	24 4	17 3	10 1	63 6
95	19 4	33 1	13 7	20 0	19 7	3 4	69 0
122	20 5	36 0	15 5	29 9	21 4	6 7	83 4
17x	19 6	30 2	10 6	27 3	19 3	3 7	48 7
27	19 6	29 7	10 1	21 2	14 4	6 1	46 4
58	19 7	27 9	8 2	23 4	10 6	3 8	54 2
73	19 7	29 7	10 0	24 5	16 1	4 6	52 0
x 22	19 8	31 1	11 3	20 4	6 5	1 1	45 5
149	19 8	24 3	4 5	19 5	10 4	1 9	39 5
141	19 9	31 2	11 3	24 0	15 8	8 0	66 2
30	19 9	43 6	23 7	26 3		3 1	77 7
54	19 9	32 5	12 6	22 4	21 3	1 3	68 7
x 24	20 2	38 7	18 5	22 2	11 1	2 6	69 7
77	20 5	36 0	15 5	25 2	26 7	8 1	85 9
x 21y	20 9	57 4	36 5	24 9	24 0	7 7	77 1
147	21 0	47 8	26 8	40 3	37 8	8 8	79 6
104	21 7	45 3	23 6	23 7	17 5	10 1	63 6
26	21 9	50 0	28 1	32 0	24 3	6 2	88 5
62	21 9	45 2	23 3	30 5	27 6	11 9	86 1
42	22 5	57 6	35 1	43 1	30 2	17 7	91 0
28	26 9	50 5	23 6	29 0	15 6	11 8	80 4

TABLE II

SOILS ARRANGED IN ORDER OF THEIR LOWER LIQUID LIMIT

Soil No	Lower liquid limit	Lower plastic limit	Plastic number	Volumetric change	Moisture equivalent	Susp clay	Total clay
x 60	17 6	14 0	3 6	15 4	12 2	3 7	63 8
21x	21 2	15 4	5 8	9 3	15 5	2 8	28 4
32	21 9	14 7	7 2	12 4	17 7	7 2	71 0
220	22 8	14 2	8 6	13 1	13 5	0 5	25 7
81	23 4	16 6	6 8	13 3	16 6	1 2	33 8
76	23 5	16 3	7 2	16 5	15 6	3 5	40 0
x 15x	23 8	18 6	5 2	10 5	20 7	3 3	47 5
139	24 0	15 2	8 8	13 8	20 0	4 5	49 7
149	24 3	19 8	4 5	10 4	19 5	1 9	39 5
x128	26 4	14 8	11 6	13 9	18 9	2 3	48 3
83	27 0	17 1	9 9	17 0	19 6	2 9	50 8
x 60x	27 4	17 0	10 4	14 8	21 3	6 8	43 6
59	27 9	16 2	11 7	15 7	19 6	5 5	43 7
58	27 9	19 7	8 2	10 6	23 4	3 8	54 2
168	28 4	17 3	11 1	18 5	16 8	2 9	48 3
x 74	28 6	18 2	10 4	15 3	17 9	4 9	39 3
25	28 8	18 3	10 5	12 5	18 0	2 8	57 7
75	29 0	16 4	12 6	17 5	18 6	3 0	50 7
11	29 1	17 8	11 3	17 4	21 8	4 6	65 1
150	29 2	17 6	11 6	15 4	21 0	11 1	57 5
127	29 3	16 3	13 0	20 9	21 2	9 3	42 9
71	29 7	17 0	12 7	15 8	21 6	4 1	58 5
27	29 7	19 6	10 1	14 4	21 2	6 1	46 4
73	29 7	19 7	10 0	16 1	24 5	4 6	52 0
x 57	29 8	15 0	14 8	21 2	20 5	3 9	47 8
x 16	29 9	15 5	14 4	18 9	19 2	2 9	48 8
34	30 0	17 4	12 6	13 8	25 4	7 4	59 9
79	30 1	16 3	13 8	17 7	23 6		
148	30 1	19 4	10 7	16 3	24 0	8 1	53 1
17x	30 2	19 6	10 6	19 3	27 3	3 7	48 7
86	30 8	17 1	13 7	20 1	20 6	4 7	47 5
66y	31 1	18 5	12 6	21 3	23 0	10 0	65 0
x 22	31 1	19 8	11 3	6 5	20 4	1 1	45 5
141	31 2	19 9	11 3	15 8	24 0	8 0	66 2
x 72	32 2	16 7	15 5	21 2	20 4	6 7	56 9
54	32 5	19 9	12 6	21 3	22 4	1 3	68 7
17y	32 7	19 8	12 9	11 9	16 5	1 7	51 4
61	32 8	18 0	14 8	20 8	26 2	8 0	63 7
140	33 0	18 8	14 2	19 1	24 3	8 7	58 3
95	33 1	19 4	13 7	19 7	20 0	3 4	69 0
x 15	33 8	16 7	17 1	17 7	21 3	8 6	52 3
85	34 5	16 7	17 8	21 7	22 1	5 5	52 4
120	34 9	18 7	16 2	24 6	24 3	6 7	69 4
122	36 0	20 5	15 5	21 4	20 9	6 7	83 4
77	36 0	20 5	15 5	26 7	25 2	8 1	85 9
x119	36 3	18 0	18 3	22 8	21 6	6 3	60 9
x 31	38 5	18 5	20 0	26 1	23 2	3 3	73 3
x 24	38 7	20 2	18 5	11 1	22 2	2 6	69 7
x 63	39 6	17 8	21 8	28 1	25 7	13 7	59 5
103	39 6	19 4	20 2	17 3	24 4	10 1	63 6
x 33	42 0	18 8	23 2	24 0	27 6	6 6	70 6
30	43 6	19 9	23 7		26 3	3 1	77 7
x 29	45 2	18 5	26 7	25 7	25 5	3 8	82 0
62	45 2	21 9	23 3	27 6	30 5	11 9	86 1
104	45 3	21 7	23 6	17 5	23 7	10 1	63 6
147	47 8	21 0	26 8	37 8	40 3	8 8	79 6
26	50 0	21 9	28 1	24 3	32 0	6 2	88 5
28	50 5	26 9	23 6	15 6	29 0	11 8	80 4
x 21y	57 4	20 9	36 5	24 0	24 9	7 7	77 1
42	57 6	22 5	35 1	30 2	43 1	17 7	91 0

order as shown by the lower plastic limit The lower plastic limit, the lower liquid limit and the moisture equivalent seem to agree more closely than do the Atterberg plastic index, the volumetric change and the clay content

Table II shows a second grouping of these same soil data, grouping them in the order of, their lower liquid limit This is a distinctly better grouping, showing a more uniform relationship than before There are still a few soils that show diverse results, but the volumetric change, clay content and plastic index follow in a much more even sequence The crosses showing bad road conditions are still scattered but much the larger number occur toward the latter part of the table where the worst soil conditions should show in the analyses

In attempting to define limits beyond which these various tests seem to show suspicious soils the following appears to be a fair statement in the sixty soils shown in these two tables

11 have a lower plastic index than 10
4 have a lower lower plastic limit than 15
9 have a lower lower liquid limit than 25
9 have a lower moisture equivalent than 18
9 have a lower volumetric change than 13
9 have a lower clay content than 45

It would seem a safe thing to view with suspicion any soil which gave greater characteristic tests than the limits above set whenever three or more of the tests agreed in the verdict

In Table II where the soils are arranged in the order of their increasing values of the lower liquid limit, if they are arbitrarily divided into six groups of ten soils each, and the values averaged, the averages show a successive increase in values of all the characteristics

TABLE III
AVERAGE VALUES OF SOIL CHARACTERISTICS

Group No	Number of soils	Lower liquid limit	Lower plastic limit	Plastic index	Volumetric change	Moisture equivalent	Suspended clay	Total clay
1	10	22 9	16 0	6 9	12 9	17 0	3 1	44 8
2	10	28 3	17 6	10 8	15 5	19 8	4 8	51 1
3	10	29 8	17 6	12 3	17 4	22 8	5 6	*50 9*
4	10	32 0	18 8	13 3	17 8	*21 8*	*5 4*	59 2
5	10	36 8	*18 7*	18 1	21 7	23 1	7 2	67 0
6	10	48 5	21 4	27 1	25 2	30 3	8 8	79 7

A study of Table III shows but four cases where the general increase in value does not take place With a larger number of soils examined and a larger number of soils in each group, there would

TABLE IV

SOIL ANALYSES AT 20 STATIONS WHERE ROAD CONDITIONS ARE BAD

Soil	L L L	L P L	Pl No	Vol Ch	Moist E	Average moisture at 12 ins	Sand	Silt	Clay
60	17 6	14 0	3 6	15 4	12 2	17 1	13 5	22 7	63 8
15x	23 8	18 6	5 2	10 5	20 7		16 1	29 2	54 7
78	24 8	14 7	10 1	14 9	18 7	19 1	20 6	24 6	54 8
128	26 4	14 8	11 6	13 9	18 9	12 9	17 1	34 6	48 3
83	27 0	17 1	9 9	17 0	19 6	16 9	25 8	23 4	50 8
60x	27 4	17 0	10 4	14 8	21 3	17 1	19 8	36 6	43 6
74	28 6	18 2	10 4	15 3	17 9	23 4	29 4	31 3	39 3
25	28 8	18 3	10 5	12 5	18 0	16 5	26 6	15 7	57 7
57	29 8	15 0	14 8	21 3	22 4	15 6	12 2	19 1	68 7
16	29 9	15 5	14 4	18 9	19 2	13 3	19 8	31 4	48 8
22	31 1	19 8	11 3		20 4	14 6	24 3	30 2	45 5
72	32 2	16 7	15 5	21 2	20 4	21 5	16 9	26 2	56 9
15	33 8	16 7	17 1	17 7	21 3	21 5	17 1	30 6	52 3
21	35 2	18 1	17 1	20 2	22 3	17 7	3 4	37 6	59 0
119	36 3	18 0	18 3	22 8	21 6	20 0	9 6	29 5	60 9
31	38 5	18 5	20 0	26 1	23 2	19 5	10 2	16 5	73 3
63	39 6	17 8	21 8	28 1	25 7	19 5	15 6	24 9	59 5
33	42 0	18 8	23 2	24 0	27 6	22 7	0 3	29 0	70 6
62	45 2	21 9	23 3	27 6	30 5	30 4	3 0	10 9	86 2
21y	49 7	20 8	28 9	24 0	24 9	13 7	11 8	11 1	77 1

Grouping the above table into four groups and averaging, the following results are obtained

Group									
1	23 9	15 8	8 1	14 3	18 0	16 5	18 6	26 9	54 5
2	28 9	16 8	12 1	16 6	19 8	17 2	21 6	26 8	51 6
3	33 7	17 9	15 9	20 5	21 2	19 1	14 3	30 8	54 9
4	43 0	19 6	23 4	26 0	26 4	21 2	8 2	18 5	73 3

undoubtedly be less variation in the constant increase in the characteristic values

An attempt to correlate the characteristics by grouping Table I guided by the lower plastic limit, does not secure nearly so concordant results

From this study it would appear that the lower liquid limit and the volumetric change tests give the safest results for comparing soils.

Note that group No 1, in Table III, holds all the soils below the average limits as set by the comparison previously mentioned

Table IV presents the soil characteristics of the soils from twenty different road stations where the bad conditions are noted, arranged in the order of increasing lower liquid limits Grouping this table and arranging as is shown at the bottom of the table, illustrates quite clearly the fact that the principal soil tests now being made do classify the soils fairly well when groups are arranged. It also illustrates in conjunction with the main part of Table IV that there are some particular physical conditions of the soil which have not yet been considered and which do influence the individual results Apparently some phase of shape, size or condition of soil grain influences results more than the *amount* of clay or suspended clay and silt seem to suggest

CONCLUSIONS

1 The lower liquid limit is the safest guide of the three Atterberg tests

2 That of the seven tests discussed in this paper, three, the lower liquid limit, the lower plastic limit and the volumetric change, appear to classify the soil in the safest manner

3 That in the light of the data presented there has not yet been developed any single soil test that will unerringly determine whether a particular soil will cause serious subgrade troubles.

4 That until such a soil test is discovered it will be well to consider with suspicion all soils whose tests show values greater than 25 for the *Lower Liquid Limit,* greater than 15 for the *Lower Plastic Limit,* greater than 10 for the *Atterberg Plastic Index,* greater than 13 for the *Volumetric Change* and greater than 18 for the *Moisture Equivalent* Especially will it be safe to draw such conclusions if three or more tests upon the same soil agree in the verdict

5 Apparently some characteristics of the soil, such as the shape, size or roughness of the soil grain, in some cases have more influence upon the test values than does the amount of the ultra or total clay

Appended are road condition comments and Figures 1 and 2 showing relations between Atterberg limits and other tests

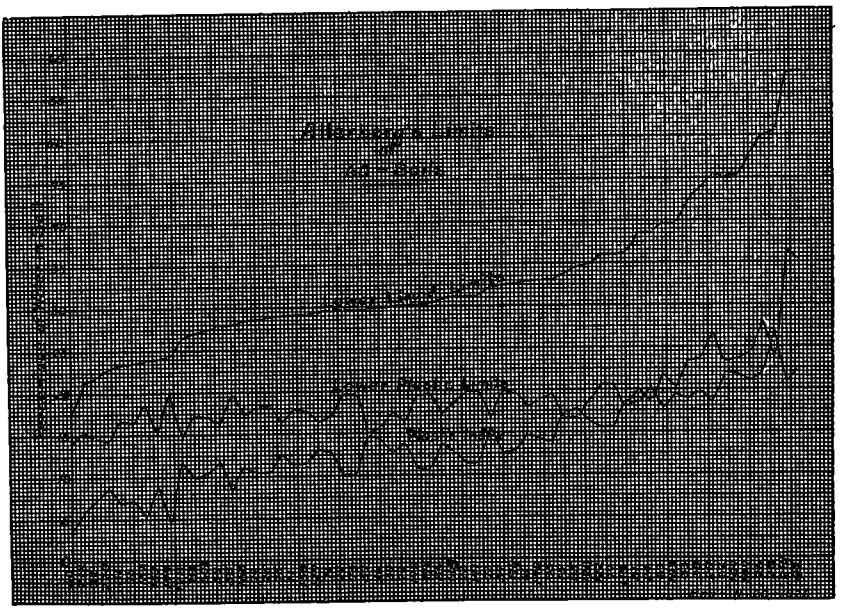

Figure 1

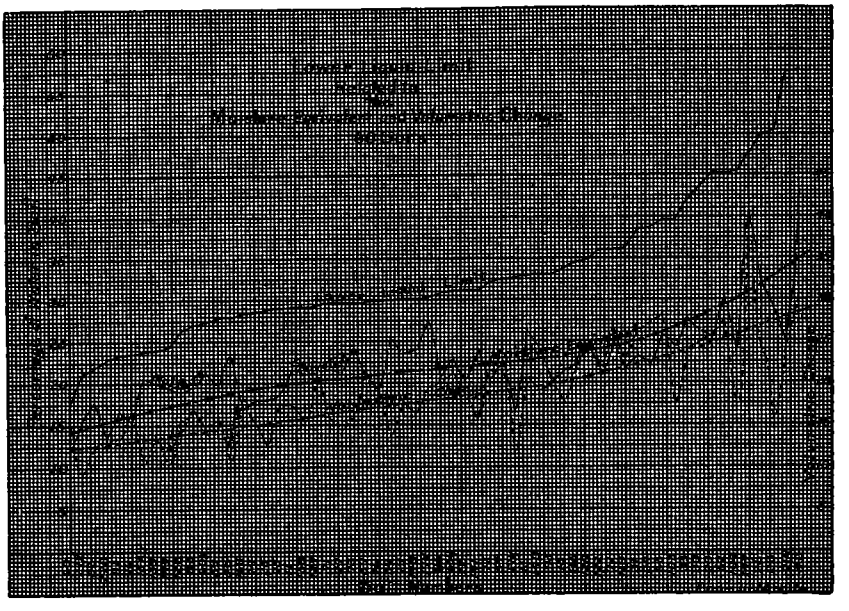

Figure 2

ROAD CONDITIONS AT VARIOUS STATIONS

Station 15x, 14 miles east of Columbus, Route 20, bituminous macadam Badly broken in 1920 and 1921 Repaired each season Was again resurfaced in 1925 Heaved badly in 1925

Station 15, 14 miles east of Columbus, Route 20, bituminous macadam Subgrade soils boiled through the pavement in spring of 1920 and 1921 Was entirely resurfaced in 1922 Resurfaced in 1925

Station 16, 20 miles east of Columbus, Route 20, bituminous macadam Badly broken up in 1920 and 1921 and was entirely replaced Has done well since replacement

Station 128, 4 6 miles west of Newark, Route 20, concrete This station is in a deep cut, partially lying on a dense blue clay Was badly broken up for last two or three years A new concrete pavement was laid on top of it in 1926 This has always been a bad spot according to the memories of the oldest settlers

Station 21y, 1 9 miles east of Zanesville, National Pike, brick The brick surface is becoming rough and badly depressed beneath the wheel tracks at either edge Repairs and resurfacing done at various points for some distance along this location

Station 21, 4 miles east of Zanesville, National Pike, brick This section is in a cut Has broken up rather badly Large patches have been repaved and considerable surface patching done Drainage poor

Station 21x, 3 25 miles east of Zanesville, National Pike, brick Some displacement here, and cold patch and replacement work done

Station 22, at the west limits of Lloydsville, National Pike, brick This is in a cut on one side, but graded off level on the other This pavement is badly displaced Large patches have been relaid and others resurfaced with cold patch

Station 24, about 0 9 mile west of Station 22, National Pike, brick Considerable patching has been done here

Station 25, 1 7 miles west of Station 22, National Pike, brick A number of repairs have been made on this hill This is right at the crest of a hill, as are most of the broken up sections

Station 31, 11 0 miles east of Cambridge, National Pike, bituminous macadam This is on a hillside at the eastern edge of Elizabethtown, a small village, and has a deep cut into the hill on one side but is graded off, but not on fill, on the other side It has required considerable repair in the past year

Section 33, 3 1 miles south of Cambridge, Route 8, concrete This pavement has not been laid many years Is in fair condition The road lies in a four or five foot cut The farmer says this was originally one of the worst spots along that road and that carloads of cinders and gravel were used to make the old road passable

Station 119, 4 15 miles west of Marietta, Route 26, new concrete This is the new road laid in 1924 It is in good condition, excepting that more cracks showed in and around station 119 than in any other places on the subbase experimental work

Station 103-104-120 and 168 all are on Route 26, new concrete Are simply included because the soil had given trouble upon the old earth road before the pavement was laid

Station 57, 3 2 miles south of Centerburg, 3 C's Route, bituminous macadam This road was very rough and broken in the spring of 1926 Required extensive repairs

Stations 60 and 60x, 10 5 miles east of Canton, Route 19, brick. These two stations are about 0 3 mile apart The pavement for several thousand feet is badly broken up and displaced It is under severe traffic, is poorly drained and has required much repairs

Stations 61-62-63, are from 8 to 15 miles east of Randolph, Route 17 Bituminous macadam These soils are similar, the country is fairly level and poorly drained The road is and has been more or less displaced by poor drainage conditions and is therefore very rough The worst conditions are at Station 63 lying about 4 miles east of Deerfield

Station 72, at south limits of Hudson, Route 91, brick This lies in a slight cut 2 or 3 feet deep The drainage is poor The road has been badly broken up and repaired so many times with concrete that it is difficult to say what the original pavement may have been.

Station 74, 1 5 miles west of the east line of Cuyahoga County, Route 15, concrete This is all broken to pieces and preparations for rebuilding are now in progress

Station 75, 5 miles east of west line of Geauga County, Route 15, concrete Has had considerable repair

Station 77, 14 miles east of west line of Geauga County, Route 15, old concrete Has had considerable repair done upon it

Station 83, half mile west of Chardon, Route 85 New bituminous macadam Shows some movement of the macadam making the road uneven Is located on hillside

The rest of the stations given in Table II are either very new or else show no serious defects as yet