REFERENCES

1. F. Netterberg. *Calcrete in Road Construction.* Council on Scientific and Industrial Research Report RR 286, National Institute for Road Research Bulletin 10. Pretoria, South Africa, 1971.
2. R. L. Mitchell. Flexible Pavement Design in Zimbabwe. *Proc., Institution of Civil Engineers,* Part 1, 12, London, Aug. 1982, pp. 333-354.
3. *A Guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-Tropical Countries.* Road Note 31. Department of Transport, Transport and Road Research Laboratory, HM Stationery Office, London, 1977.
4. J. R. Hosking and L. W. Tubey. *Research on Low-Grade and Unsound Aggregates.* Laboratory Report LR 293. Department of Transport, Transport and Road Research Laboratory, Crowthorne, England, 1969.
5. *Standard Methods of Testing Road Construction Materials.* TMH1. National Institute for Transport and Road Research, Council on Scientific and Industrial Research, Pretoria, South Africa, 1979.
6. *Methods of Test for Soils for Civil Engineering Purposes.* BS 1377. British Standards Institution, London, 1975.
7. *Methods for Sampling and Testing of Mineral Aggregates, Sands and Fillers.* BS 812 (three parts). British Standards Institution, London, 1975.
8. S. J. Emery. Prediction of Pavement Moisture Content in Southern Africa. *Proc., 8th Regional Conference for Africa on Soil Mechanics and Foundation Engineering,* Vol. 1, Harare, Zimbabwe, 1984, pp. 239-250.
9. H. R. Smith and C. R. Jones. *Measurement of Pavement Deflections in Tropical and Sub-Tropical Climates.* Laboratory Report 935. Transport and Road Research Laboratory, Crowthorne, England, 1980.
10. S. W. Abaynayaka. Calibrating and Standardising Road Roughness Measurements Made With Response Type Instruments. *Proc., International Conference on Roads and Development,* Paris, May 22-25, 1984, (Presses de l'école national des ponts et chaussées), pp. 13-18.
11. *A Guide to the Measurement of Axle Loads in Developing Countries Using a Portable Weighbridge.* Road Note 40. Department of Transport, Transport and Road Research Laboratory, HM Stationery Office, London, 1978.
12. C. J. Lawrance and T. Toole. *The Location, Selection and Use of Calcrete for Bituminous Road Construction in Botswana.* Laboratory Report 1122. Department of Transport, Transport and Road Research Laboratory, Crowthorne, England, 1984.
13. *Structural Design of Interurban and Rural Road Pavements.* Draft TRH 14. National Institute for Transport and Road Research, Council on Scientific and Industrial Research, Pretoria, South Africa, 1980.

An Aggregate Thickness Design That Is Based on Field and Laboratory Data

BERNARD D. ALKIRE

A summary is provided of the results of a research program sponsored by the Federal Highway Administration entitled "Design and Operation of Aggregate-Surfaced Roads." Major emphasis is devoted to correlating field and laboratory data and developing the Clegg Impact device as an alternative method for determining in-place density and strength evaluation. Twelve sites in Michigan, Iowa, Texas, Oregon, North Dakota, Montana, West Virginia, and South Carolina were selected for tests. The determination of sites included a variety of climatic and subgrade conditions to allow these factors to be included in the analysis. Field data collected at each field site included roadway dimensions, thickness of the aggregate surface, Clegg Impact Values, in-place density, and moisture content. Bag samples of subgrade and surface aggregate were collected for laboratory tests that included classification tests, gradation, durability, abrasion tests, Clegg Impact Value, and California Bearing Ratio (CBR). Results from laboratory and field tests were analyzed to develop relationships between the various test parameters. A regression analysis of laboratory results showed good agreement between Clegg Impact Value and CBR. The relationship that was developed compared with the results given by Clegg in his work. Statistical relationships that related surface and subgrade conditions in the field to Clegg Impact Value and field moisture content were also obtained and were related to the equation for aggregate thickness design. A discussion that relates the results to the design of low-volume, aggregate-surfaced roads is included.

Millions of miles of roads in the United States are aggregate surfaced. In most cases they have relatively low traffic levels and depend on inexpensive design, construction, and maintenance. Maximum use of local materials and empirical procedures that are based on experience are required to minimize cost.

The results discussed in this paper were collected as part of a project to develop a design procedure for aggregate-surfaced

---

Michigan Technological University, Houghton, Michigan 49931.

roads that includes a consideration of traffic and climate. In developing the design procedure, information on the state of the practice in the design and operation of aggregate-surfaced roads was collected. This involved field visits to 12 locations around the continental United States. The locations that were selected covered a variety of conditions and were chosen to establish a data base on aggregate-surfaced roads that considered climate, surface mixtures, thickness, and maintenance. Part of this project involved the collection of field data related to road conditions, dimensions, and materials. This required field tests at the site as well as laboratory tests on samples taken at the field site.

The information collected during the field visit was used to develop a simple design procedure for aggregate-surfaced roads. The design procedure is related to results from the field and laboratory tests on the aggregates.

TESTS

Sites within the continental United States were selected to obtain field data relative to existing practices in the design and operation of aggregate-surfaced roads. At each site, the project personnel talked with a local contact, who was usually a county engineer, but in several areas the contacts were state highway engineers or National Forest Service engineers. The contacts at each site provided basic information about the area and general engineering practices related to aggregate-surfaced roads. The first field visits were made in the summer of 1984. Follow-up visits to most of the sites were made in the spring of 1985.

Test sites were selected to provide at least one site in each of the climatic zones defined in the paper by Carpenter et al. (*1*). This scheme uses the concept of potential evapotranspiration and divides the country into zones in which similar pavements receive similar climatic input. The zones are shown in Figure 1. In this figure the Roman numerals indicate moisture regions (I = subgrade soil saturated all year, II = seasonal wet-dry periods in subgrade soil, and III = dry subgrade soil). The capital letter refers to temperature regimes (A = severe winter; B = moderate winter, freeze-thaw; and C = mild winter).

Field Tests

The field test locations were selected from typical aggregate-surfaced roads at each test site. Certain field data were collected at each test location and included the following:

- Thickness of the aggregate surface;
- Surface aggregate Clegg Impact Value at centerline, wheel path, and edge of aggregate surface;
- Surface aggregate density and moisture content at the wheel path;
- Subgrade density and moisture content at the wheel path; and
- Subgrade Clegg Impact Value at the wheel path location.

The test procedure that was used to take the Clegg Impact Value is described elsewhere, but basically involved taking the fourth blow value from the meter attached to the device (*2, 3*).

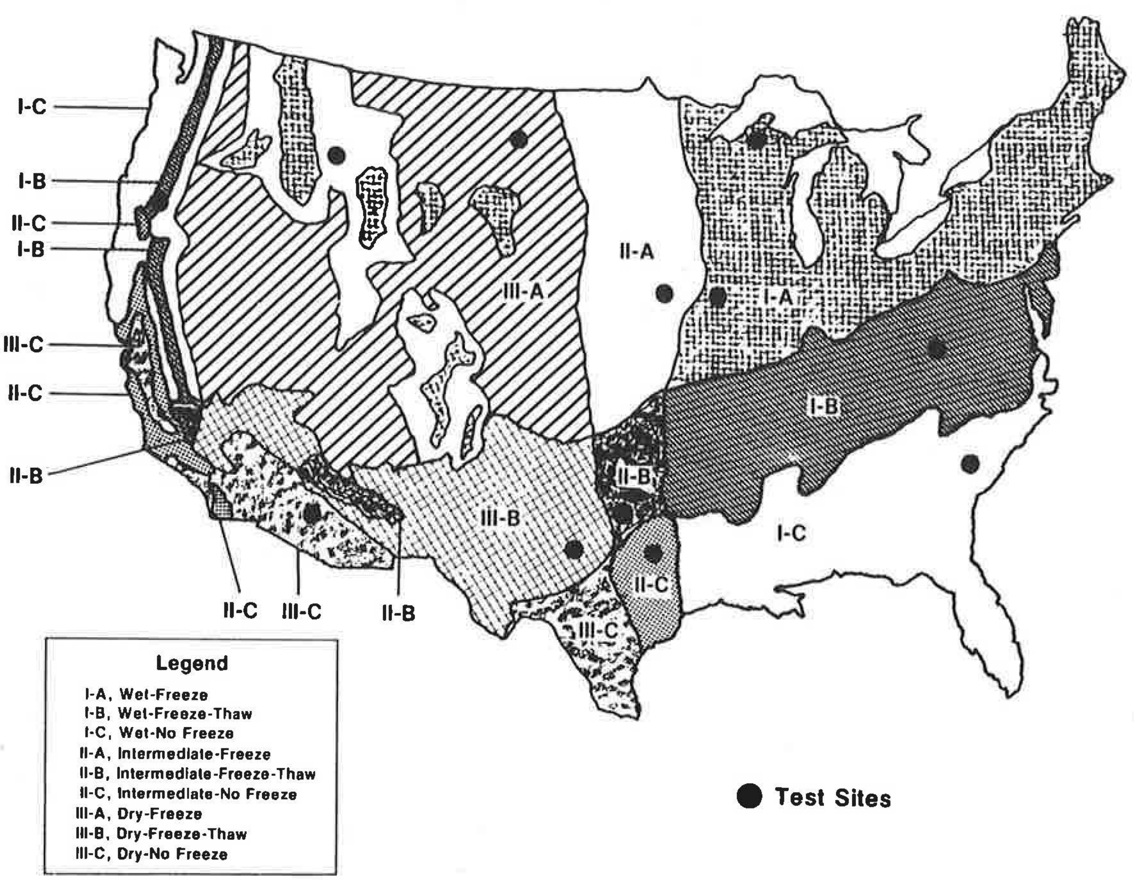

FIGURE 1 Climatic zones and field test sites.

The in-place density was determined by using SAE 10-40 motor oil to measure the volume of the excavated hole. Moisture was determined from sealed bag samples that were taken at the test site and sent back to the laboratory. Subgrade moisture, density, and Clegg Impact Values were taken by digging through the surface aggregate to the top of the subgrade and conducting the tests at that depth. The results from the field tests are summarized in Table 1. A list is provided in this table of the time of the visit, the location of each test, and field test values for the subgrade and surface soil. It can be seen that there is a wide variation in test values but the subgrade water content is higher and the Clegg Impact Value is lower than for the surface. In addition, the surface water content is usually below 10 percent and the subgrade value is above 10 percent. Surface aggregate depth varies from less than 1 in (25 mm) to over 12 in (305 mm).

TABLE 1 SUMMARY OF FIELD TEST RESULTS

			Subgrade Soil			Surface Aggregate			
County, State (Climatic Zone)	Test	Time^a of Yr.	Water Content (%)	Dry Density (pcf)	Clegg Impact Value	Water Content (%)	Dry Density (pcf)	Clegg Impact Value	Aggregate Thickness (in.)
Wapello, IA	D	SU	21	NA	10	3	NA	44	3.5
(IA)	D	SP	21	103	27	10	104	59	4.0
	E	SU	6	NA	26	2	NA	54	2.0
	E	SP	3	139	25	3	136	56	2.0
	J	SU	13	NA	27	4	NA	43	2.0
	J	SP	15	104	28	4	127	F	1.0
	L	SU	17	NA	14	8	112	39	4.0
	L	SP	19	92	28	6	110	F	4.0
	Q	SU	17	NA	27	7	146	18	1.3
	Q	SP	21	NA	44	4	NA	F	1.0
Shelby, IA	BB	SU	17	NA	19	4	121	23	3.0
(IIA)	BB	SP	17	97	10	18	94	8	1.0
	DD	SU	16	NA	18	6	90	27	2.5
	DD	SP	18	101	11	10	110	34	NA
	SS	SU	14	NA	13	9	124	14	0.5
	SS	SP	15	104	8	14	108	8	1.0
	VV	SU	19	NA	10	6	138	36	5.25
	VV	SP	20	99	11	8	113	68	2.50
Kanawha, WV	5	SU	9	NA	19	2	133	47	5.0
(IIB)	5-C	SP	18	105	7	4	110	43	6.0
	8	SU	6	130	38	2	134	87	8.0
	8	SP	21	121	21	7	113	42	5.0
Lexington, SC	20	SU	4	132	36	2	126	54	2.0
(IC)	20	SP	5	134	34	2	145	50	2.0
Collin, TX	1	SU	17	71	11	4	110	24	7.0
(IIB)	1	SP	11	108	31	7	112	33	7.0
Smith, TX	11	SU	9	128	30	14	128	27	8.0
(IIC)	11	SP	8	98	18	12	108	21	8.0
Custer NF, ND	13	SU	16	93	12	4	120	75	6.0
(IIIA)	13	SP	10	121	17	9	128	49	5.0
	14	SU	10	112	24	11	85	35	3.0
	14	SP	12	107	24	22	104	24	2.0

TABLE 1 *continued*

			Subgrade Soil			Surface Aggregate			
County, State (Climatic Zone)	Test	Time[a] of Yr.	Water Content (%)	Dry Density (pcf)	Clegg Impact Value	Water Content (%)	Dry Density (pcf)	Clegg Impact Value	Aggregate Thickness (in.)
Taylor, TX	5	SU	12	100	22	1	NA	52	6.0
(IIIB)	4	SP	13	111	17	3	122	26	3.0
	11	SU	9	106	24	2	136	54	6.0
	11	SP	13	107	30	3	122	47	4.5
Lolo NF, MT	38	SU	9	138	46	4	145	59	4.5
(IIB)	38	SP	10	132	NA	5	147	NA	4.8
	208	SU	7	135	40	3	146	68	9.0
	208	SP	10	137	NA	5	144	NA	9.0
	Petty	SU	5	116	12	3	139	92	10.0
	Petty	SP	5	115	NA	7	135	NA	10.0
Klamath, OR	2	SU	17	68	20	4	130	55	8.0
(IIIC)	2	SP	21	89	16	6	115	48	7.0
	10	SU	NA	NA	NA	3	125	44	12.5
	10	SP	30	70	6	3	137	43	11.0
	18	SU	16	NA	19	2	NA	26	6.0
	18	SP	16	99	14	6	74	24	6.0

NOTE: NA = not available, F = soil frozen at time of test

[a] SP = Spring 1985, SU = Summer 1984

Laboratory Tests

Bag samples of the surface aggregate and subgrade soil were collected at each test site for laboratory analysis. The soil from each site was tested to determine the grain size, liquid and plastic limit, optimum water content, maximum dry unit weight (ASTM D1557), and Clegg Impact Value at the maximum dry unit weight. The data from these tests are summarized in Table 2 for the surface aggregates and Table 3 for the subgrade soils. It can be seen from these data that the surface aggregates are generally classified as gravels or sands with optimum water content below 10 percent. Maximum dry unit weights are in the 130 to 140 pcf (20.4 to 22.0 kN/m^3) range and Clegg Impact Values are in the 40 to 50 range. The subgrade soils have a wider range of classifications, generally higher optimum water content, and lower maximum dry densities at optimum.

A good part of the laboratory testing was done to develop the relationship between the CBR and the Clegg Impact Value. The results of the laboratory CBR tests on nonsoaked subgrade soils are presented in Table 4. Each of the 21 subgrade soils was tested for three different moisture contents. The Clegg Impact Value is the average of the fourth readings obtained from the top and bottom of the molded sample.

STATISTICAL RELATIONSHIPS

A simple linear regression analysis of the field data was performed in an attempt to develop functional relationships between test parameters. Of particular interest are the relationships of Clegg Impact Value versus moisture content and CBR versus Clegg Impact Value.

Clegg Impact Tests and Field Moisture Content

Several combinations of factors were used in the analysis of the data to isolate the effect of soil type and time of test. First, all soils and field test times were analyzed as one group. Then, various soil groups were considered separately and, finally, the data for a given soil group were analyzed by subdividing them into results from field tests in the summer of 1984 and spring of 1985. In this way, it was possible to determine the relationship for all soils and compare it to the relationship for a particular soil at a particular time.

The relationships between subgrade soil field water content and measured field Clegg Impact Value are given in Table 5. It can be seen that all fine-grained soils and sands have a negative relationship between Clegg Impact Value and the water per-

TABLE 2 SUMMARY OF SURFACE AGGREGATE TEST RESULTS FROM LABORATORY TESTS

County, State (Climatic Zone)	Test	USCS Subgrade Soil Class	Passing #200 (%)	Plastic Limit (%)	Liquid Limit (%)	Optimum Water Content (%)	Maximum Modified Dry Density (pcf)	Clegg Impact Value
Wapello, IA	D	GM-GC	16	14	18	5.4	142	38
(IA)	E	GM-GC	13	13	19			
	J	SM	16	NP	17			
	L	GM-GC	27	18	22	7.1	130	61
	Q	SM-SC	21	11	17	5.6	140	47
Shelby, IA	BB	SC	38	19	30			
(IIA)	DD	SM-SC	19	16	22			
	SS	GP	9	17	21	7.0	135	39
	VV	SM-SC	20	17	22	6.9	135	42
Kanawha, WV	5	SM-SC	22	18	22	6.0	140	36
(IB)	8	GM	15	NP	15	5.8	144	42
Lexington, SC	20	SP-SM	9	NP	8	6.3	136	45
(IC)								
Collin, TX	1	GC	28	18	29	12.4	118	45
(IIB)								
Smith, TX	11	SC	25	NP	NL	13.1	134	43
(IIC)								
Custer NF, ND	13	SM-SC	35	19	24	10.9	130	39
(IIIA)	14	SM	21	NP	NL	25.6	95	41
Taylor, TX	5	SM-SC	27	19	14	6.7	132	54
(IIIB)	11	SC	27	16	25	7.1	134	39
Lolo NF, MT	38	GM	14	24	32	3.8	139	48
(IIB)	208	GP	12	NP	20	5.0	145	40
	Petty	GM	16	NP	20	6.7	136	40
Klamath, OR	2	SW	10	20	27	9.2	131	35
(IIIC)	10	SM	14	NP	24	8.2	145	37
	18	SP-SM	10	NP	NL	14.4	115	40

NOTE: NP = no plastic limit, NL = no liquid limit

centage. This is expected because the Clegg Impact Value is a measure of subgrade strength, and soils tend to lose strength as water content increases. It can also be seen that higher Clegg Impact Values and the highest correlation coefficients are associated with the sandy soils and the summer readings.

It appears that the gravelly soils do not behave in the same manner as the others. This could be the result of innate differences in the material or could be related to the limited amount of data on this soils classification. In addition, it was not possible to determine the effect of time on the gravelly soil because the spring 1985 data were collected by a field team that did not have a Clegg Impact device.

The influence of climatic zone on the Clegg Impact Value is shown in Table 6. Inspection of this table reveals several factors of interest. It can be seen that the poorest correlation coefficients are associated with soils in the cold-wet zones. For example all areas in Zone I (severe winter) have a correlation coefficient of 0.35 compared to 0.74 for the areas in Zone III (moderate winter). Likewise, the areas in Zone A (wet) have a coefficient of 0.15 whereas the areas in Zone C (dry) have a value of 0.88. This illustrates the more consistent subgrade conditions found in the warm, dry climates. It also can be seen that the subgrade Clegg Impact Values are higher in the warm, dry climates. By inference, it could be predicted that warm, dry climates should have better roads with fewer problems related to subgrade strength.

TABLE 3 SUMMARY OF SUBGRADE TEST RESULTS FROM LABORATORY TESTS

County, State (Climatic Zone)	Test	USCS Subgrade Soil Class	Passing #200 (%)	Plastic Limit (%)	Liquid Limit (%)	Optimum Water Content (%)	Maximum Modified Dry Density (%)	Clegg Impact Value
Wapello, IA	D	CL	79	22	44		NA	
(IA)	E	GC	19	17	26			
	J	SM	36	26	32			
	L	CL	78	22	38	11.7	113	39
	Q	ML	82	27	38	14.9	110	37
Shelby, IA	BB	CL	96	23	36			
(IIA)	DD	CL	90	23	40			
	SS	SC	40	18	40	10.4	112	36
	VV	CL	93	25	45	13.0	112	39
Kanawha, WV	5	ML	57	23	30	11.0	127	27
(IB)	8	SM-SC	22	13	19	6.4	130	36
Lexington, SC	20	SM	32	NP	15	9.2	128	37
(IC)								
Collin, TX	1	CL	60	22	44	17	109	36
(IIB)								
Smith, TX	11	SM	25	NP	NL	10.4	125	30
(IIC)								
Custer NF, ND	13	CL	54	19	34	10.4	115	35
(IIIA)	14	ML	71	NP	24	13.0	118	23
Taylor, TX	5	CL	77	19	29	11.1	121	40
(IIIB)	11	SC	38	22	34	9.9	124	27
Lolo NF, MT	38	GM-GC	25	19	25	6.7	133	44
(IIB)	208	GM	21	23	25	6.5	128	34
	Petty	GM	20	NP	30	6.9	132	39
Klamath, OR	2	SM	19	2	39	17	107	32
(IIIC)	10	ML	NA	NA	NA	16	107	38
	18	SW-SM	10	NP	NL	30	75	35

NOTE: NP = no plastic limit, NL = no liquid limit, NA = not available

California Bearing Ratio and Clegg Impact Value

The 62 data points that represent the CBR and Clegg Impact Values obtained from laboratory tests (Table 4) were also analyzed by use of regression equations. The results from this analysis are tabulated as follows:

Equation Number	*Equation*	*Correlation Coefficient*
1	$\log CBR = -0.649 + 1.67 \log CIV$	0.94
2	$CBR = 3.35 + 0.0803 CIV^2$	0.88

Based on the correlation coefficient values, the best fit is the following log-log equation:

$$\log CBR = -0.649 + 1.67 \log CIV \tag{1}$$

or its equivalent

$$CBR = 0.2244 CIV^{1.67} \tag{2}$$

which is comparable to the equation proposed by Clegg (*2*)

$$CBR = 0.07 CIV^2 \tag{3}$$

TABLE 4 NONSOAKED CALIFORNIA BEARING RATIO LABORATORY TEST RESULTS FOR SUBGRADE SOILS

County, State	Test	Moisture Content (%)	Dry Density (pcf)	California Bearing Ratio	Clegg Impact Value
Klamath, OR	2	11.1	103.0	103	38
		18.4	102.6	3	7
		18.8	102.0	1	2
	10	15.6	105.4	142	36
		17.7	105.3	26	18
		20.7	100.0	3	6
	18	23.1	78.9	88	27
		24.5	79.8	36	18
		28.0	77.6	8	11
		29.8	77.3	2	7
		34.0	72.4	1	1
Lolo NF[a], MT	38	3.8	126.1	113	25
		8.0	129.7	41	22
		10.0	125.7	3	8
	208	2.1	122.9	144	28
		5.6	125.6	129	32
		9.5	122.2	11	10
	Petty	3.2	122.8	74	27
		4.5	127.5	84	30
		8.8	128.7	7	13
		9.4	127.2	3	8
		9.7	126.8	3	7
Custer NF[a], ND	13	7.6	109.1	58	28
		9.8	113.8	36	23
		22.9	97.6	3	4
	14	10.0	114.2	34	23
		12.8	112.2	11	12
		16.8	107.3	2	5
Collin, TX	1	7.2	101.4	38	NA
		17.	104.4	29	NA
		22.2	100.8	10	NA
Fannin, TX	9	7.9	115.6	88	36
		11.3	118.0	26	20
		15.5	109.6	2	4
Smith, TX	11	7.9	115.2	66	28
		11.3	121.6	17	12
		14.0	115.9	3	4

TABLE 4 continued

County, State	Test	Moisture Content (%)	Dry Density (pcf)	California Bearing Ratio	Clegg Impact Value
Smith, TX	11	4.7	107.6	17	13
		11.1	109.6	2	10
		14.1	102.2	1	2
Taylor, TX	5	8.3	116.7	78	34
		11.2	121.4	45	27
		15.5	114.8	5	7
	11	7.0	120.3	71	36
		10.4	121.7	25	NA
		13.5	116.1	3	5
Kanawha, WV	5	5.7	116.6	66	NA
		10.1	120.2	41	NA
		14.3	118.6	7	NA
	8	6.9	125.6	96	NA
		8.4	129.0	38	23
		11.1	122.2	3	7
Lexington, SC	14	6.4	111.6	81	33
		13.1	116.0	20	14
		17.6	109.5	2	3
	17	3.8	116.1	27	13
		7.5	119.6	28	12
		7.8	118.4	20	11
		12.7	115.6	3	4
	20	3.7	113.7	33	15
		9.4	104.8	48	22
		14.8	90.5	1	2
Houghton, MI	Massie	3.4	132.4	78	36
		6.5	142.7	107	34
		7.3	141.9	91	28
		9.2	138.2	12	12
	Massie	5.6	114.7	37	25
		7.0	119.9	56	27
		9.5	124.4	63	34
		12.4	115.2	6	11

[a] NF = National Forest

NOTE: NA = not available

TABLE 5 FIELD CLEGG IMPACT VALUES FOR SUBGRADE SOILS AS A FUNCTION OF WATER CONTENT, SOIL TYPE, AND SEASON

Soil Classification	Time	Regression Equation	Correlation Coefficient	Number of Data Points
All	All	CIV = 34.7 - 1.04 w	0.61	43
CL	All	CIV = 28.2 - 0.68 w	0.32	15
	SU	CIV = 38.1 - 1.40 w	0.78	8
	SP	CIV = 23.1 - 0.26 w	0.13	8
SM, SC SM-SC	All	CIV = 38.8 - 1.31 w	0.70	17
	SU	CIV = 43.4 - 1.61 w	0.86	8
	SP	CIV = 32.6 - 0.81 w	0.42	7
ML	All	CIV = 21.8 - 0.40 w	0.27	6
GM-GC GM, GC	All	CIV = 2.5 + 4.6 w	0.75	8

NOTE: SU = Summer 1984
SP = Spring 1985
CIV = Clegg Impact Value
w = moisture content in percent

TABLE 6 FIELD CLEGG IMPACT VALUE FOR SUBGRADE SOILS AS A FUNCTION OF WATER CONTENT AND CLIMATIC ZONE

Climatic Zone	Regression Equation	Correlation Coefficient	Number of Data Points
IA	CIV = 24.7 - 5.00 w	0.0	10
IIA	CIV = 14.6 - 0.10 w	0.26	8
IIIA	CIV = 36.3 - 1.42 w	0.68	4
IB	CIV = 37.3 - 1.18 w	0.66	4
IIB	CIV = 38.40 - 1.06 w	0.31	5
IIIB	CIV = 25.16 - 0.16 w	0.0	4
IC	INSUFFICIENT DATA		2
IIC	INSUFFICIENT DATA		2
IIIC	CIV = 29.8 - .76 w	0.86	5
All I	CIV = 32.1 - 0.52 w	0.35	16
All II	CIV = 39.3 - 1.49 w	0.61	15
All III	CIV = 31.0 - 0.82 w	0.74	13
All A	CIV = 23.6 - 0.29 w	0.15	22
All B	CIV = 39.00 - 1.22 w	0.49	13
All C	CIV = 36.00 - 1.05 w	0.88	9

CIV = Clegg Impact Value
w = moisture content in percent

All three equations and the data points from Table 4 are plotted on Figure 2. It can be seen that all equations can be used to approximate the laboratory test results. However, Equation 3 is suggested because it is easy to use and is familiar to many engineers.

The results from the regression analysis on the laboratory test samples show that several relationships between CBR and Clegg Impact Value are possible. In the next section a method of determining aggregate thickness is developed that uses the relationships that were developed in this section.

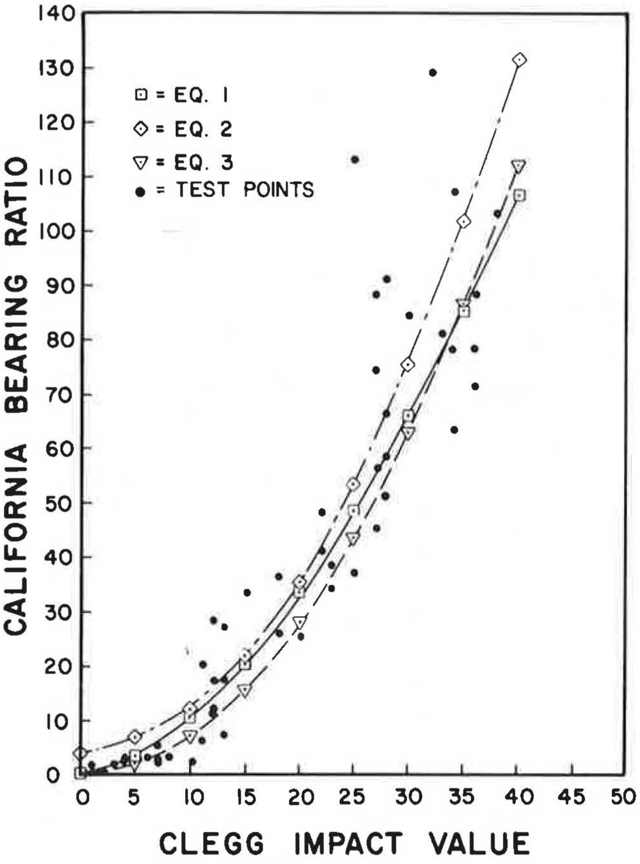

FIGURE 2 Unsoaked California Bearing Ratio versus Clegg Impact Value regression relationships.

AGGREGATE THICKNESS DESIGN

It is possible to estimate layer thickness for an aggregate-surfaced road based on experience to achieve a simple design. Interviews with county engineers suggest that this is the technique that is being used by many local governmental agencies. Unfortunately, it is impossible to incorporate this type of information into a systematic design because of the infinite number of possibilities that exist. A simple model will be proposed instead and it will be used to calculate aggregate thickness for general situations. The results can then be used to verify existing designs or they can be used for new designs when tempered with the experience of the local engineer.

A model that has been used for aggregate roads that incorporates the main factors that affect thickness is the U.S. Army Corps of Engineers model (*4*). The equation for this model is as follows:

$$t = f[(P/8.1*CBR) - (A/\pi)]^{1/2} \qquad (4)$$

where

t = aggregate thickness (in),
P = single wheel load (lb),
A = tire contact area (in^2),
f = factor to account for traffic and rut depth, and
CBR = California Bearing Ratio of the subgrade soil at the critical moisture content.

The f factor is determined empirically; for a 3-in (76-mm) rut depth failure criterion, Equation 4 becomes:

$$t = (.176 \log W_{18} + .120)(1111.1/CBR - 35.82)^{1/2} \qquad (5)$$

when

W_{18} = the number of 18-kip (8100-kg) equivalent single-axle load applications to failure,
P = 9000 lb (4050 kg), and
A = tire contact area = 112.5 in^2 (730 cm^2).

This equation for thickness directly accounts for traffic and subgrade strength.

Inspection of Equation 5 suggests some simplification is necessary. The first term in parentheses determines the effect of the number of load repetitions on thickness. The value of this term is 1 for 100,000 load applications and is only 40 percent greater for 10 million load applications. On the other hand, when the CBR is reduced from 10 to 3, the thickness is doubled. Therefore, it appears that the main area of interest should be in adequately describing the subgrade soils. In that case it is possible to simplify Equation 5 to the following:

$$t = [750/CBR]^{1/2} \qquad (6)$$

This equation compares favorably with Equation 5 and is much easier to use. The relationship between Equations 5 and 6 is shown in Figure 3. It can be seen that at low CBRs, Equation 6 falls between the values from Equation 5 for 15,000 and 90,000 equivalent axle loads. At CBRs greater than 10, Equation 6 is more conservative by a small amount, and at a CBR of 100 the required thickness calculated using Equation 6 would be 3 in (75 mm).

In order to make thickness a function of Clegg Impact Value, Equations 1, 2, or 3 can be substituted into Equation 6. If Equation 3 is assumed to be correct, by substituting and rounding, Equation 6 becomes the following:

$$t = 100/CIV \qquad (7)$$

It is also possible to use the regression equations that relate Clegg Impact Value to subgrade soil types and in situ moisture (w, in percent) to develop simple relationships to determine aggregate thickness. For example, using the regression equation for all soil types and all times (Table 5),

$$t = 100/(34.7 - w) \qquad (8)$$

or for CL soil in the spring

$$t = 100/(23.1 - w) \qquad (9)$$

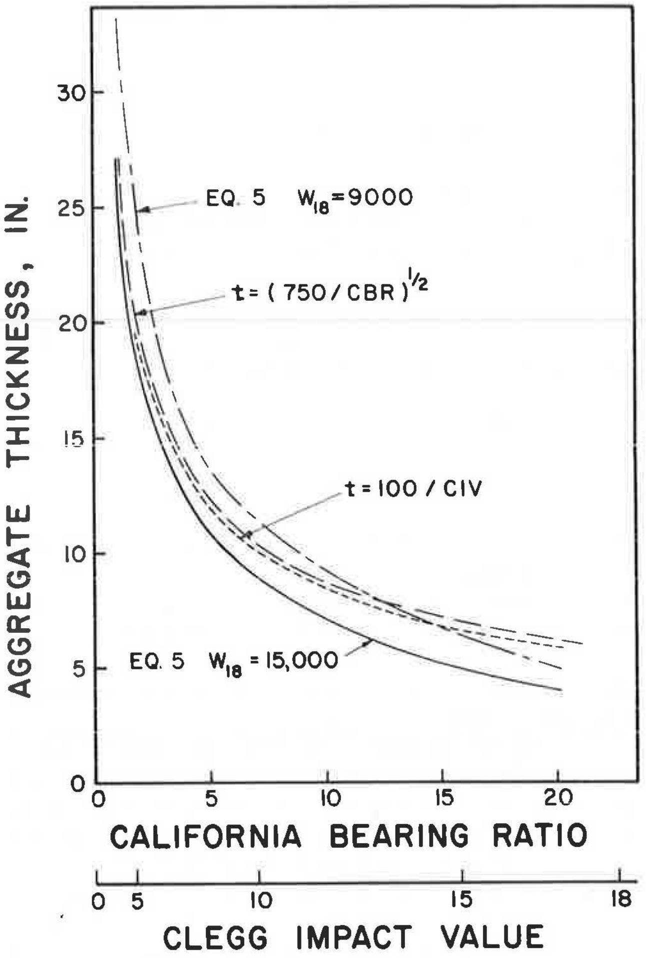

FIGURE 3 Aggregate thickness versus California Bearing Ratio or Clegg Impact Value.

These equations emphasize the problems associated with aggregate thickness design based on in situ soil characteristics. Because the Clegg Impact Value, or w in Equations 7, 8, and 9, is not a constant for a given soil some engineering judgment has to be incorporated into the design. The conservative approach would be to use the lowest Clegg Impact Value or the highest w measured in the field or obtained from laboratory samples prepared at standard critical conditions, such as the soaked CBR test. This usually leads to over-design and calculated thicknesses that are substantially greater than the actual values determined in the field. A more realistic approach is to use a concept comparable to that of accumulated damage and base the design thickness on a weighted average value that accounts for the variability of the Clegg Impact Value with the season (5).

$$WCIV = \sum_{i=1}^{n} F_i \, CIV_i \, \Delta t_i \Big/ \sum_{i=1}^{n} \Delta t_i \qquad (10)$$

where

$WCIV$ = weighted average Clegg Impact Value,
F_i = seasonal weighting factor for ith time interval,
CIV_i = average Clegg Impact Value in ith time interval, and
Δt_i = ith time interval.

For example, when Figure 4 is used to determine the average Clegg Impact Value and with F_i equal to 1, the following results:

$$\begin{aligned} WCIV &= ((1 \times 20 \times 1) + (1 \times 5 \times 2) \\ &\quad + (1 \times 15 \times 7) + (1 \times 50 \times 2))/(1 + 2 \\ &\quad + 7 + 2) \\ &= 19.6 \end{aligned}$$

Then, with $CIV = WCIV$, Equation 7 becomes

$$t = 100/WCIV \qquad (11)$$

Therefore, the required aggregate thickness for the example just given would be 5.1 in (129.5 mm) compared to the 20 in (508.0 mm) required if the lowest value of Clegg Impact Value (5) is used.

It is difficult to relate this suggested method to the field test results because there are so many different climatic zones and soil types. Data are also insufficient to define the curve of Clegg Impact Value versus time. However, it is indicated in Figure 4 (obtained from actual field measurements) that the weighted average Clegg Impact Value occurs during the summer months and it might be possible to use a single Clegg Impact Value to describe the subgrade soil.

If it is assumed that the summer Clegg Impact Value obtained during the field visits is typical of the weighted average value, the required thickness of aggregate can be calculated using Equation 8 and compared to the actual aggregate thickness. The results of this comparison are tabulated in Table 7 and plotted in Figure 5. In analyzing the data obtained from this comparison, the square of the correlation coefficient between the actual values and the points calculated using Equation 8 is 0.4. This indicates a poor correlation between observed aggregate thickness and the calculated values. The reason for the poor correlation is because an incorrect seasonal weighting factor of 1 was used instead of the actual value that fits local conditions.

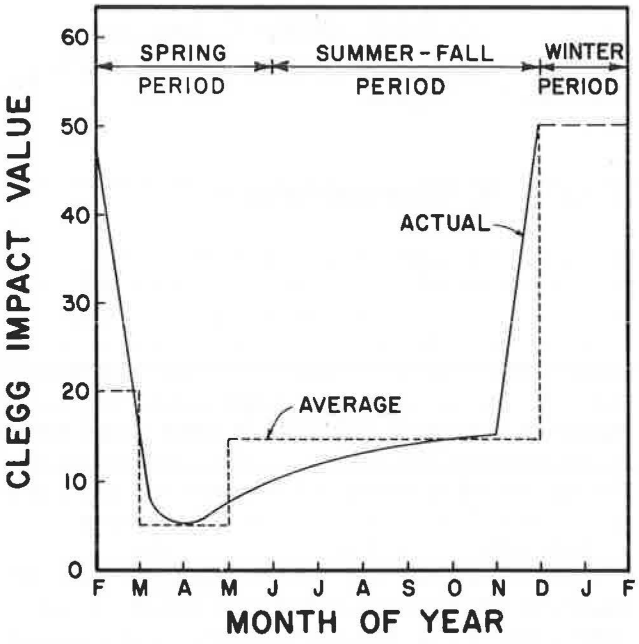

FIGURE 4 Subgrade strength versus time of the year.

TABLE 7 CALCULATED SEASONAL WEIGHTING FACTORS FOR DIFFERENT CLIMATIC ZONES

Location (Climatic Zone)	Test	Subgrade Soil Classification	CIV_{su}	Actual Aggregate Thickness (in.)	Calculate[a] Aggregate Thickness (in.)	Calculated[b] F_i
Wapello, IA	D	CL	10	3.5	10.0	2.9
(IA)	E	GC	26	2.0	3.8	1.9
	J	SM	27	2.0	3.7	1.9
	L	CL	14	4.0	7.1	1.8
	Q	SC	27	1.3	3.7	2.8
Zone Average			21	2.6	5.7	2.3
Shelby, IA	DD	CL	18	2.5	5.6	2.2
(IIA)	SS	SC	13	0.5	7.7	15.4
	VV	CL	10	5.3	10.0	1.9
	BB	CL	19	3.0	5.3	1.5
Zone Average			15	3.6	7.2	1.9
Custer NF, ND	13	CL	12	6.0	8.3	1.4
(IIIA)	14	ML	24	3.0	4.2	1.4
Zone Average			18	4.5	6.2	1.4
Kanawha, WV	5	ML	19	5.0	5.3	1.1
(IB)	8	SM-SC	38	8.0	2.6	0.3
Zone Average			29	6.5	4.0	0.7
Collins, TX	1	CL	11	7.0	9.1	1.3
(IIB)						
Taylor, TX	5	LL	22	6.0	4.5	0.8
(IIIB)	11	SC	24	6.0	4.2	0.7
Zone Average			23	6.0	4.7	.8
Lexington, SC		SM	36	2.0	2.8	1.4
(IC)						
Smith, TX	11	SM	30	8.0	3.3	0.4
(IIC)						
Klamath, OR	2	SM	26	8.0	3.8	0.5
(IIIC)	10	ML	10[c]	12.5	10.0	0.8
	18	SW-SM	19	6.0	5.3	0.9
Zone Average			18	8.8	6.4	.7

[a] $t_{calc} = \frac{100}{CIV_{su}}$

[b] $F_i = \frac{100}{t_{actual}\ CIV_{su}}$

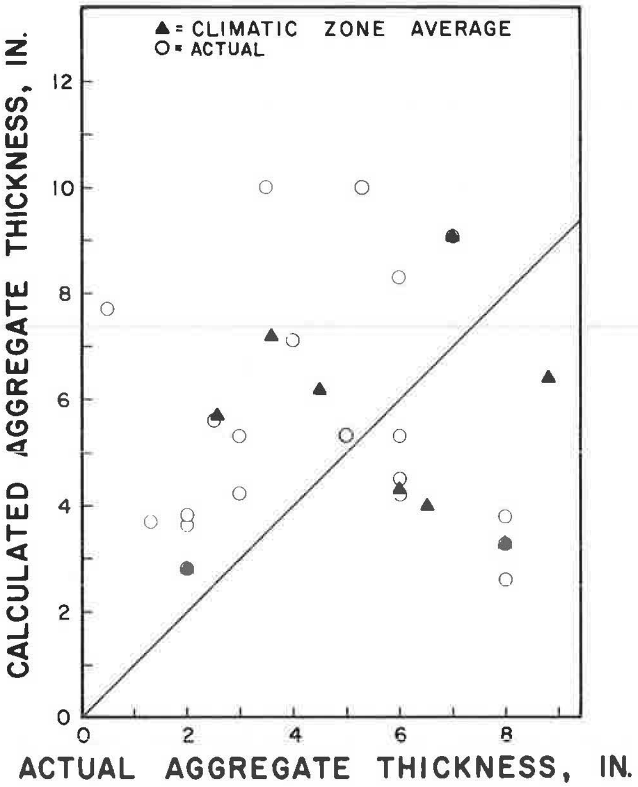

FIGURE 5 Calculated versus actual aggregate thickness.

To determine the average seasonal weighting factor for the different climatic zones, the observed aggregate thickness and the summer Clegg Impact Value were substituted into Equation 8, and an average seasonal weighting factor, F_i, was back-calculated. The results of this calculation are also shown in Table 7. It is shown in Table 7 that the cold climatic regions have high values for the seasonal weighting factor. It can also be seen that there is a fair variation of values within any climatic zone.

A matrix of average values for the seasonal weighting factor and calculated and observed aggregate thickness for each climatic zone is shown in Table 8. It can be seen that the roads in warm, dry climatic zones generally use more aggregate. The least amount of aggregate is associated with the data collected at Lexington County, South Carolina, in climatic zone IC.

The averages of all values are also shown in Table 8. It can be seen that the average observed thickness is 5.4 in (137.2 mm) compared to 5.3 in (134.6 mm) for the calculated thickness. An improvement in the relationship between calculated and observed thickness can therefore be made if the average Clegg Impact Value for each climatic zone is used to determine the resulting thickness. These values are shown by the darkened symbols plotted on Figure 5. In this case, the relation between the calculated and observed aggregate thickness is higher with a correlation coefficient of 0.7. Therefore, Equation 8 is adequate for most calculations to determine aggregate thickness, if enough data can be collected to allow the local engineer to determine the average seasonal weighting factor.

TABLE 8 AVERAGE SEASONAL WEIGHTING FACTOR MATRIX

Climatic Zone	Seasonal Weighting Factor	Actual Aggregate Thickness (in.)	Calculated Aggregate Thickness (in.)
IA	2.3	2.6	5.7
IB	0.7	6.5	4.0
IC	1.4	2.0	2.8
Zone Average	1.5	3.7	4.2
IIA	1.9	3.6	7.2
IIB	1.3	7.0	9.1
IIC	0.4	8.0	3.3
Zone Average	1.2	6.2	6.5
IIIA	1.4	4.5	6.2
IIIB	0.8	6.0	4.3
IIIC	0.7	8.8	6.4
Zone Average	1.0	6.4	5.2
Average of all	1.2	5.4	5.4

The one item of interest to the engineer that has not been mentioned is how the roads performed in relation to their thickness. During each of the site visits, the project personnel made a subjective evaluation of the condition of all sections that were tested. At the time of the field visits, all of the test sites were in good condition. There were no restrictions on driving speed or comfort and no indications of subgrade failures. The only observed performance problem was at a site in Iowa at which the roads were slippery when wet. However, this is more likely related to the aggregate gradation rather than an insufficient aggregate thickness.

The fact that the roads were in good condition might indicate that the roads were adequately designed for the level of traffic that they were carrying. It might also indicate that the roads were over-designed and aggregate was being wasted. It is impossible to determine which case is correct. However, the fact that the cold, wet climatic zones have less aggregate, and still have passable roads, suggests that many of the aggregate roads that are currently being constructed are somewhat over-designed.

SUMMARY

A simple aggregate thickness design procedure was suggested. The design was based on the Corps of Engineers equations for low-volume roads and requires an indication of the subgrade strength in terms of the subgrade Clegg Impact Value.

Subgrade strength was determined in this paper by use of the Clegg Impact device and the relationships between CBR and Clegg Impact Value were developed from laboratory tests on collected field samples. It was shown that Clegg's relationship that related Clegg Impact Value to CBR was suitable to describe the soil for the sites tested.

Field results were used to show that the thickness design equations could be simplified to an inverse function of a weighted Clegg Impact Value (Equation 8) that incorporated climatic conditions into the design equation through a seasonal weighting factor.

The suggested design procedure can be made site-specific if one collects enough data to accurately define the weighted Clegg Impact Value for particular climatic conditions. This value can then be used to determine the aggregate thickness based on particular local conditions instead of the data collected in this research.

ACKNOWLEDGMENTS

The work presented in this paper was developed as part of a project sponsored by the Federal Highway Administration entitled "Design and Operation of Aggregate-Surfaced Roads." Their support is gratefully acknowledged. Laboratory tests were performed by Jerome Breyer.

REFERENCES

1. S. H. Carpenter, M. I. Darter, and B. J. Dempsey. Evaluation of Pavement Systems for Moisture-Accelerated Distress. In *Transportation Research Record 705*, TRB, National Research Council, Washington, D.C., 1979.
2. B. Clegg. An Impact Soil Test for Low Cost Roads. *Proc., 2nd Road Engineering Association of Asia and Australia*, Manila, Philippines, 1978.
3. B. Clegg. Application of an Impact Test to Field Evaluation of Marginal Base Course Material. In *Transportation Research Record 898*, TRB, National Research Council, Washington, D.C., 1983.
4. *Thickness Requirement for Unsurfaced Roads and Airfields.* TRS 70-5. U.S. Army Corps of Engineers, Waterway Experimental Station, Vicksburg, Mississippi, 1970.
5. *Surfacing Handbook*. FSH 7709.569. U.S. Forest Service, U.S. Department of Agriculture, Washington, D.C., 1983.