L-4/T-1/CE **Date: 23/04/2024**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-1 B. Sc. Engineering Examinations 2021-2022

Sub: **CE 401** (Project Planning and Construction Management)

Full Marks: 280 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.

(Assume any reasonable value of missing data)

1. (a) The network of a Civil Engineering construction project is shown in Figure-1 along with the duration of each activity. Compute activity time and total float of each activity and also locate the critical path on the network. **(26⅔)**

   (b) Manifest the safety measures that should be taken for Hot bituminous work. How does milestone chart differ from a bar chart? **(5+5)**

   (c) Explain Project Management Cycle with a diagram. State the advantages and shortcomings of Linear Programming method. **(5+5)**

2. (a) Draw a network diagram for the project having 9 activities, with the following interrelationships: **(10)**

   (i) A and B start at the same time, (ii) C follows B but precedes F (iii) C follows B but precedes H (iv) G follows F but precedes I (v) E follows A but precedes I (vi) D follows A (vii) H and I terminate at the same time.

   (b) A health enthusiast wishes to mix two types of foods in his diet, in such a way that vitamin content of the mixture contains at least 10 units of vitamin B and 13 units of vitamin C. Food (F1) contains 1 unit/kg of vitamin B and 2 units/kg of vitamin C. Food (F2) contains 2 unit/kg of vitamin B and contains 1 unit/kg of vitamin C. Food (F1) costs BDT 60/kg and Food (F2) costs BDT 80/kg. Frame his diet plan making a linear programming problem in order to minimize the cost of the mixture. Solve the problem by Graphical method. **(14⅔)**

   (c) A construction company has an opportunity to submit a bid for the construction of a new Residential building. From the specifications provided by the client, the PERT network along with three time estimate (in week) for each activity are shown in Figure-2. Compute Critical path and its Standard Deviation and probability of completion the project within 50 weeks. **(22)**

3. (a) What is the objective of a market survey in the feasibility study of a project? Describe the various steps to be included in the market survey. **(5+6)**

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Contd ... Q. No. 3

(b) Project X and project Y have the cash flows (BDT in Lac) shown in the following Table. **(35⅔)**

End of year	0	1	2	3	4
Project X	-20	2	6	10	14
Project Y	-30	16	12	10	8

Which project will you choose if the minimum attractive rate of return is 11% using (a) present worth method, (b) internal rate of return method, and (c) incremental rate of return method. Comment on the results.

4. (a) Explain a bad project plan with example. How a bad project plan can be salvaged? How should you articulate the objectives of a project? **(11)**

(b) What do you mean by "Cash flow diagrams"? Draw a typical cash flow diagram. What will be the future value of Tk. 200,000/- invested now at an interest rate of 9% compounded quarterly per year after 5 years? **(15⅔)**

(c) A company is considering three different methods for acquiring a truck. The alternatives are: **(20)**

(i) Purchasing the truck for Tk. 1 crore and sell it after 5 years for an estimated Tk. 30 lac.

(ii) Purchase the truck on special time payments with Tk. 25 lac down now and Tk. 30 lac per year at the end of each year for 4 years. Assume that the truck will be sold for Tk. 20 lac at the end of 5 years.

(iii) Rent the truck for 5 years for Tk. 25 lac paid in advance at the beginning of each year. If the company's MARR is 9%, which alternative should be used?

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE** questions.

5. (a) List the types of conflict that may occur in a team. Explain the conflict levels in a high-performing team with a diagram. Briefly explain Herzberg's Two-Factor Theory. **(3+7+5=15)**

(b) SWAPNO, as a retailer, sells a popular mango-flavored milk priced at BDT 125 per pack. On average, SWAPNO experiences a daily demand of 72 packs, with inventory turns of 52.14 per year. AARONG serves as the distributor for these packs, offering them to SWAPNO at a rate of BDT 50 per pack. Additionally, AARONG applies a fixed fee of BDT 500 for shipping and BDT 200 for handling per order. SWAPNO has determined a lead time of 32 days for their orders. The holding cost for maintaining inventory is BDT 7.5 annually. Considering 50 weeks are remaining in this fiscal year, how many packs should SWAPNO order at a time? Find out if the current lead time is sufficient or not. **(15)**

Contd P/3

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Contd ... Q. No. 5

(c) Differentiate between the Dialectical Inquiry Process and the Devil's Advocacy Process. **(6⅔)**

(d) Consider the following projects with a hurdle rate of 12% p.a. compounded semiannually, **(10)**

Year	Project A (BDT)	Project B (BDT)
0	-5000	-5000
1	4000	1000
2	1000	1000
3	800	1900
4	600	2200
5	300	2300

Calculate the NPV and IRR for both projects and provide your decision based on their rankings in terms of NPV and IRR, considering the following scenarios:

(i) If the projects are independent,

(ii) If the projects are mutually exclusive.

Justify your decision with proper reasoning.

6. (a) Illustrate a standard project life cycle using a flow chart and include all essential environmental regulations relevant to each stage. List down all the steps of a typical Environmental Management Plan for an urban project. **(8⅔+5=13⅔)**

(b) Define CPI and consider the following scenario, **(10)**

The typical household in our country buys 2 kg of rice, 1.5 kg of sugar and 4 kg of onion each week. The prices of these goods in the years 2021, 2022 and 2023 are given in the table below:

Year	Price of a kilogram of rice	Price of a kilogram of sugar	Price of a kilogram of onion
2021	BDT 55	BDT 73	BDT 65
2022	BDT 65	BDT 107	BDT 95
2023	BD 70	BDT 148	BDT 128

Calculate the CPI in each year using 2022 as the base year. In addition, determine the inflation in the year 2022. Comment on the change of buying pattern for a typical consumer depending on this inflation.

(c) What distinguishes financing a project through investments from financing it through debts? At which stage of the project is each method applicable? **(8)**

(d) Consider the following scenario: **(15)**

As February draws to a close, Sagor finds himself at a crucial juncture, deciding to place orders for a highly anticipated book by a popular writer for his shop, recently released at this year's book fair. Drawing upon insights from the previous year's data,

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Contd ... Q. No. 6(d)

Sagor opts to order 80% of the previous year's forecast. However, with the publisher setting the book's price at BDT 250 and a maximum retail price of BDT 375, Sagor must tread carefully to ensure profitability. Moreover, failure to sell all copies before next year's book fair would result in salvage at BDT 150 per book. Assume the demand is normally distributed over time. The following table provides a history of previous orders of this same retailer:

Product Description	Last Year's Forecast for the same writer	Actual Demand	Standard Deviation of A/F
Book 1	2000	1900	0.0962

Calculate the optimum order quantity for this book.

7. (a) What is project management? With the help of a diagram, show the elements of project management. **(3+5=8)**

(b) Who are the participants and what are their activities in the briefing stage of a construction project? What are the differences between fixed-price contracts and unit-price contracts? **(10+6=16)**

(c) Suppose you are an executive engineer of the Roads and Highways Department, Bangladesh and posted as a project manager of a national highway widening project (from 4 lanes to 8 lanes). You have to call for the tender of the construction work. What types of construction documents do you have to prepare for the bidders, and what type of documents are you expecting from the bidders? Give proper explanations. **(15⅔)**

(d) What do you understand by site overheads in construction works? Given some examples. **(7)**

8. (a) What do you understand by Work Breakdown Structure (WBS)? Suppose you are the project manager of a six-storied civil engineering laboratory building construction project at the BUET campus. Try to identify the components of this project related to concreting and create a WBS with suitable levels of detail. **(13⅔)**

(b) What are the elements of a construction master program? With proper labeling, draw a site layout plan for a building construction project. **(6+7=13)**

(c) What do you understand by repair maintenance, breakdown maintenance and preventive maintenance? Briefly describe with an example. What is meant by the prevention of future deficiency in the construction quality control process? **(6+3=9)**

(d) What are the ten construction safety rules? What are the differences between quality assurance and quality control? **(8+3=11)**

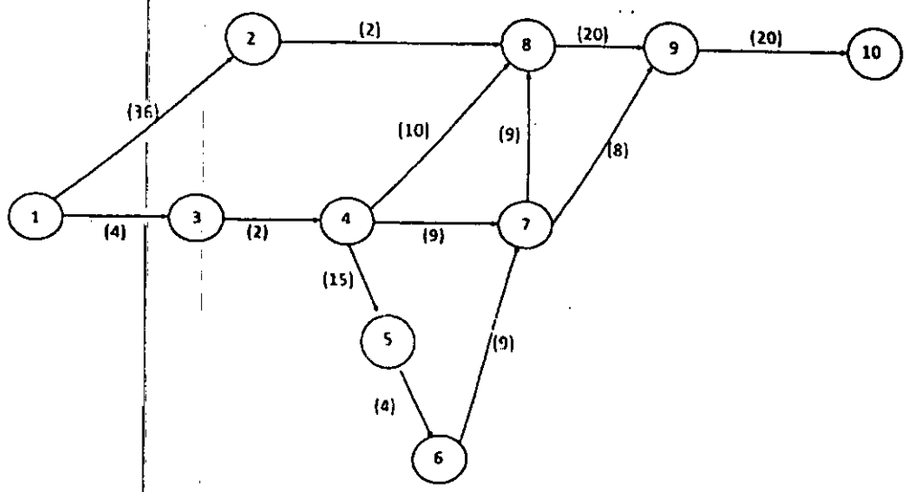

Figure – 1

Table 7·6. Standard Normal Distribution Function

Z (+)	Probability (P_r)(%)	Z (−)	Probability (P_r) (%)
0	50·0	0	50·0
+0·1	53·98	−0·1	46·02
+0·2	57·93	−0·2	42·07
+0·3	61·79	−0·3	38·21
+0·4	65·54	−0·4	34·46
+0·5	69·15	−0·5	30·85
+0·6	72·57	−0·6	27·43
+0·7	75·80	−0·7	24·20
+0·8	78·81	−0·8	21·19
+0·9	81·59	−0·9	18·41
+1·0	84·13	−1·0	15·87
+1·1	86·43	−1·1	13·57
+1·2	88·49	−1·2	11·51
+1·3	90·32	−1·3	9·68
+1·4	91·92	−1·4	8·08
+1·5	93·32	−1·5	6·68
+1·6	94·52	−1·6	5·48
+1·7	95·54	−1·7	4·46
+1·8	96·41	−1·8	3·59
+1·9	97·13	−1·9	2·87
+2·0	97·72	−2·0	2·28
+2·1	98·21	−2·1	1·79
+2·2	98·61	−2·2	1·39
+2·3	98·93	−2·3	1·07
+2·4	99·18	−2·4	0·82
+2·5	99·38	−2·5	0·62
+2·6	99·53	−2·6	0·47
+2·7	99·65	−2·7	0·35
+2·8	99·74	−2·8	0·26
+2·9	99·81	−2·9	0·19
+3·0	99·87	−3·0	0·13

Table for Q 2(c)

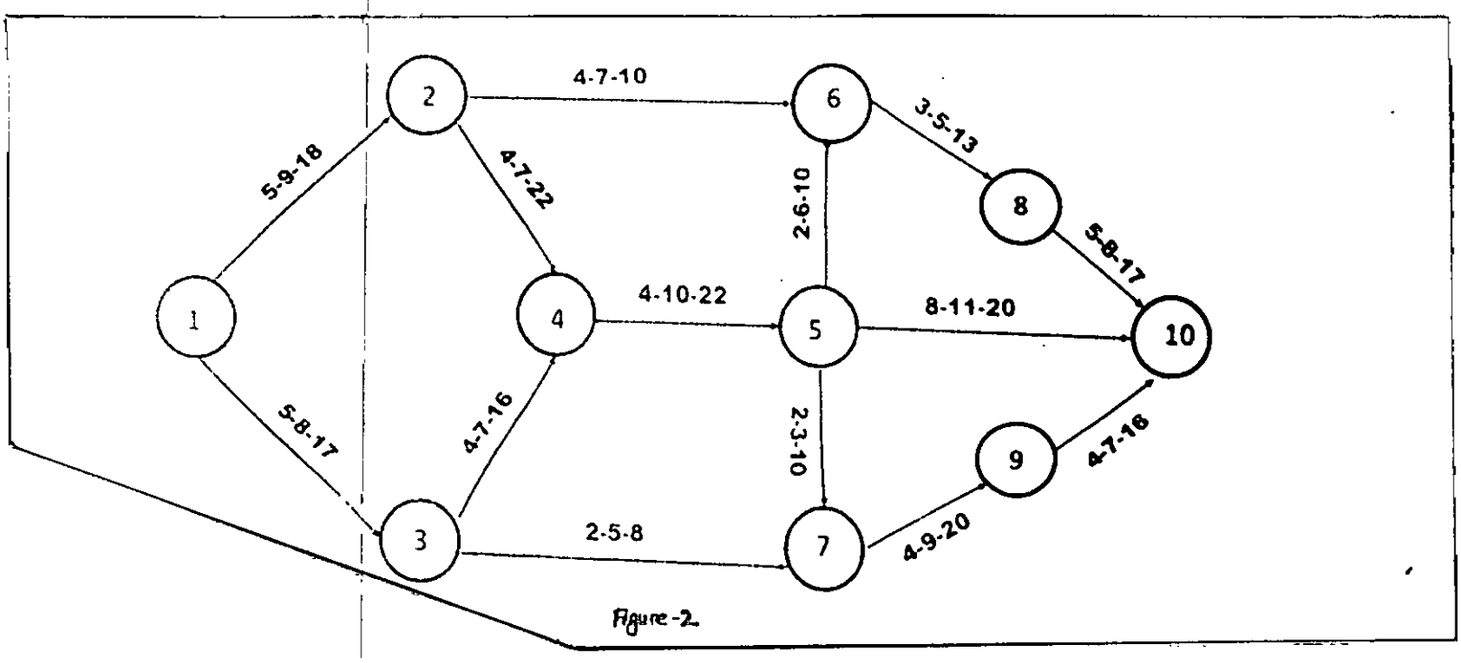

Figure -2.

Appendix

Standard Normal Distribution table for positive z

Standard Normal Distribution

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936

Table for Q. 6(d)

L-4/T-1/CE Date: ~~04/05/2024~~ 19/05/2024

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-1 B.Sc. Engineering Examinations 2022-2023

Sub: **CE 441 (Foundation Engineering)**

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

Assume any reasonable value of missing data.

1. (a) A pile group consisting of 12 piles (shown below in Figure 1, dimensions are in mm) is subjected to a total vertical load of 4500 kN, with eccentricity $e_x = 0.40$ m and $e_y = 0.30$ m. Determine the maximum and minimum loads on an individual pile. **(14+6)**

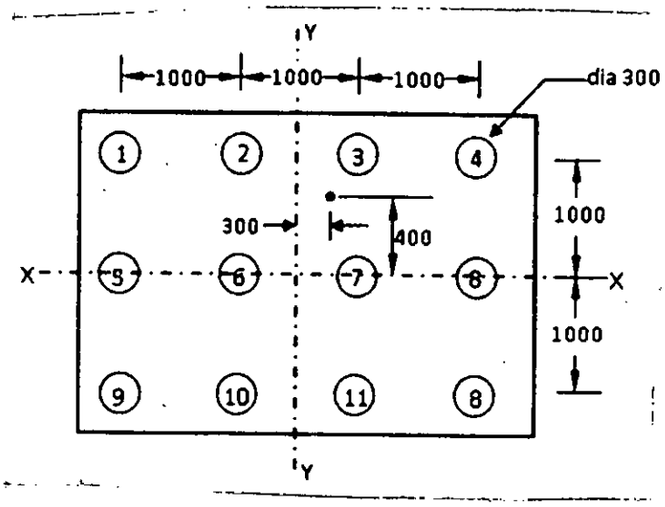

Fig. 1 For Q. No. 1(a)

If piles are precast with f'_c = 4.5 ksi and structural capacity of a pile controls the allowable capacity of an individual pile, check whether this capacity would be adequate to carry the above structural load on the group pile?

(b) Write short note on 'Piles driven in sand, the zone of influence and its extent (using relevant figure)' **(5+5+5)**

Write down the provisions of Code to define 'safe load' of an individual pile from static load test. Enumerate at least five states of subsoil conditions requiring piled foundations.

2. (a) A rectangular raft of size 12 m × 16 m is founded at a depth of 4 m below the ground surface in loose to medium dense sand (having Poisson's ratio μ= 0.3 and constrained modulus $E_s = 250(N_{cor} + 15)$ with $q_n = 120\ kN/m^2$.

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Contd ..... Q. No. 2(a)

Standard penetration tests conducted at the site gave the following corrected N_{60} values. The water table is at the base of the foundation. Above the water table $\gamma = 19.6$ kN/m^3, and submerged $\gamma_b = 10.1$ kN/m^3. Estimate the elastic settlement of footing at the center and one corner of the raft. Given: the influence factor for overburden pressure due to soil surcharge,

$$I_s = 0.66\left(D_f/B\right)^{-0.19} + 0.025\left(L/B + 12\mu - 4.6\right) \quad \textbf{(20)}$$

Depth below GL, m	2	4	6	8	10	12	14	16	18	20	22
SPT, N_{60}	8	8	12	12	11	16	18	17	20	21	20

Steinbrenner's chart is provided in Fig.2.

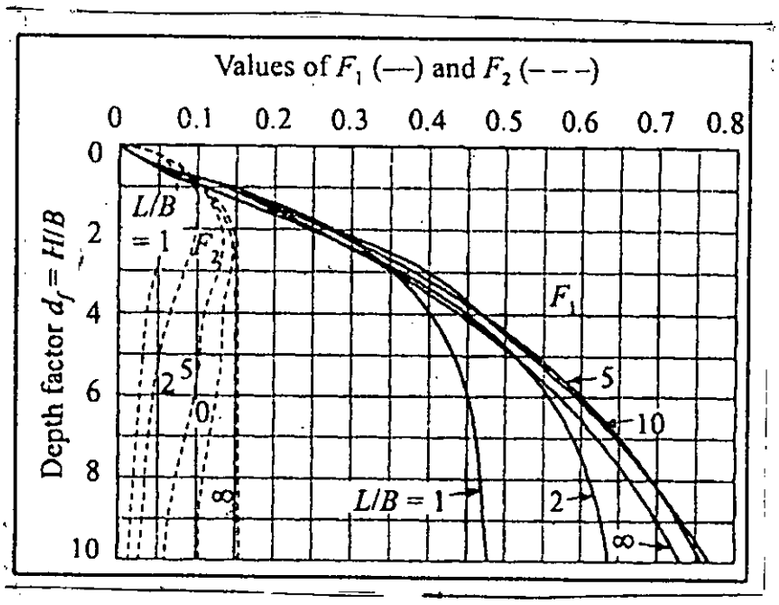

Fig. 2 For Q. No. 2(a): Settlement due to load on surface of elastic layer: F_1 and F_2 versus depth factor $d_f = H/B$ for various L/B (after Steinbrenner, 1934).

(b) In which type of soil do you need both TSA and ESA analysis to estimate Q_u of a single pile? Explain the background reasoning for both type of analysis.

Show that a cylinder of soil of annular thickness greater than 40% of the pile radius is disturbed, and hence, explain the rationality of using ϕ'_{cs} instead of ϕ'_p in the formulation of 'pile capacity estimation' in ESA analysis. **(15)**

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3. (a) Figure shown below (Fig. 3) give the plan of a footing subjected to eccentric load with two-way eccentricity. The footing is founded at a depth 3 m below the ground surface. Given, $e_x = 0.60$ m and $e_y = 0.75$ m, determine Q_{ult} in kN. The soil properties are c =0, N_{cor}=20, γ= 18.5 kN/m^3. The soil is medium dense sand. Use N_γ = 34 and N_q = 33 (Meyerhof; for ϕ= 35°); Hansen's shape and depth factors. **(20)**

Use the general shear failure with the bearing capacity factors proposed by Hansen.

Hansen's shape and depth factors are:

$$s_c = 1 + \left(N_q/N_c\right)\left(B/L\right);\ s_q = 1 + \left(B/L\right)\tan\phi;\ s_\gamma = 1 - 0.4\left(B/L\right)$$

$$d_c = 1 + 0.4\frac{D_f}{B},\ d_q = 1 + 2\tan\phi\,(1 - \sin\phi)^2\frac{D_f}{B},\ \text{and}\ d_\gamma = 1\ \text{for all}\ \phi$$

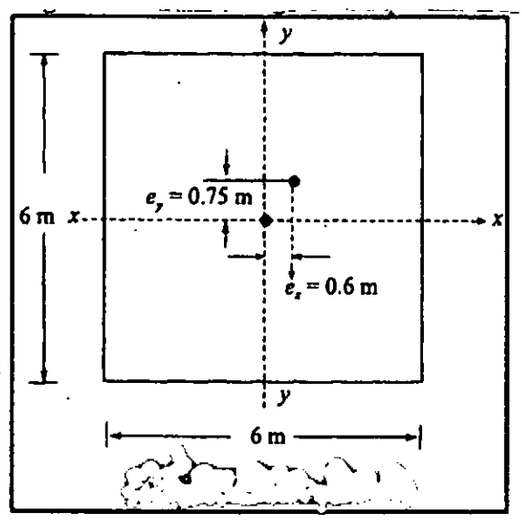

Fig. 3 For Q. No. 3(a)

(b) Static pile load test was carried out on a 16-in by 16-in concrete pile installed 21 m inot a loose-to-medium sandy soil. The pile was driven into the soil. Selected load-displacement data are shown in the table below. Draw the relevant load-settlement curve to determine: (i) the ultimate capacity of single pile, (ii) the allowable load, if the serviceability limit is 12 mm. (iii) Is the maximum load in the test similar to the ultimate load? Justify your answer. **(15)**

Load (ton)	0	34	74	110	150	185	200	234	250	260	200
Settlement (mm)	0	1.5	3.2	5.5	9.3	14.5	21.5	27.1	32.3	44.7	46.5

Load (ton)	150	100	50	0
Settlement (mm)	42.5	39.2	36.7	26.5

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4. (a) A 3 × 4 concrete pile group with a pile spacing of 1.10 m center-to-center, pile diameter of 0.5 m and 25 m long supports a load of 15.0 MN. Consider the soil profile given below (Fig-4) with a single pile installed as having a 'steel shell' in the upper layer. Note that the use of 'steel shell' is to make the upper loose soil separated from the pile itself. Determine the factor of safety for the pile group (Use: $N_q = 0.6\, e^{0.126\phi'_{cs}}$). The piles were driven. **(25)**

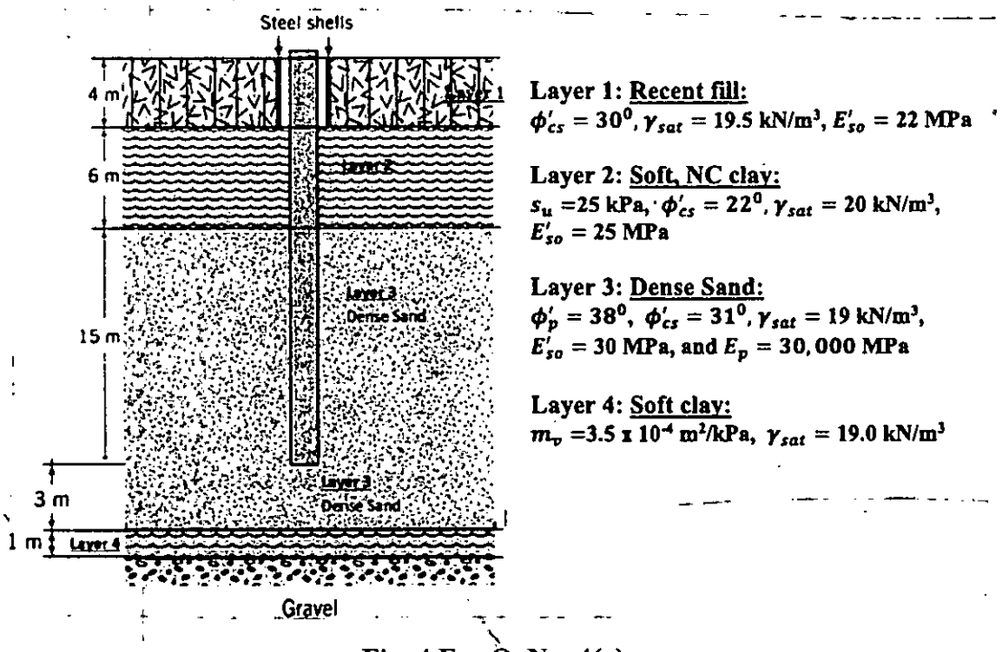

Fig. 4 For Q. No. 4(a):

(b) Estimate the elastic settlement/shorting of the group pile system mentioned in **Q. 4(a)** based on either the respective (i) allowable load **or** (ii) design load. Given E_p = 30,000 MPa. Assume that elastic modulus (E_{so}) of various soil layers are constant with the depth and neglect the elastic settlement of a pile due to end hearing. Given: **(10)**

$$\rho_{es} = \frac{Q_{af}}{E_{SO} x L} I; I = 0.5 + \log\left(\frac{L}{D}\right);$$

$$\rho_{es} = \frac{Q_{af}}{E_{SO}\, x\, D} I_p; \rho_p = C \frac{Q_{af}}{E_p\, x\, A_p} L.$$

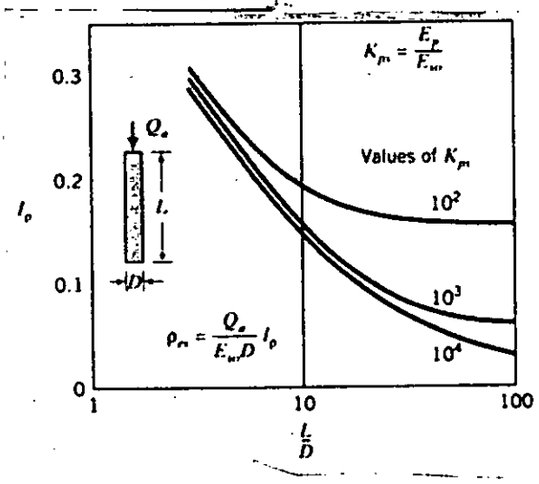

Fig. 5 For Q. No. 4(b):

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SECTION – B

There are **FOUR** questions in this section. Answer **THREE**.

5. (a) Why geotechnical investigations are necessary in the feasibility stage of any mega project? Differentiate between rotary drilling and percussion drilling. **(10)**

(b) State the basic principles of 'seismic refraction survey' and 'electrical resistivity survey' methods used for sub-soil exploration. Also, state the applicability of these methods. **(10)**

(c) Derive the expression of factor of safety for an infinite slope that makes an angle β with the horizontal considering the occurrences of seepage in the soil mass. Also, compare the factor of safety equation with the case of no seepage. How does the development of tensile crack affect the stability of slope with water? **(15)**

6. (a) Sate, with appropriate sketches, the operational process of piston sampler. Explain-how a Piston Sample provides good quality undisturbed sample compared to Shelby Tube. **(10)**

(b) Draw atypical graph showing the variation of vertical effective overburden pressure and the field Standard Penetration Number, N_F for different angle of internal friction (Schmertmann, 1975). Write down two important implications from the graph. **(10)**

(c) In the course of subsurface investigation, an SPT-N value of 12 was recorded for a clay layer situated at a depth of 25 feet. Susequently, an examination of the drilling equipment unvelled that the hammer employed by the drilling operator weighed 25 lb less than the standard weight. Is there any way to correct the measured SPT-N value? If so, give justification of the correction procedure and determine the corrected SPT-N value. **(12+3)**

List the key parameters that can be derived from the Dutch Cone Penetration test.

7. (a) Draw a typical graph showing the variation of angle of internal friction and corrected N value, N_{cor} (Hatanaka and Uchida, 1996). Write down two important implications from the graph. **(10)**

(b) What are the factors to be considered in deciding on a slope stability analysis procedure? Also, write three main causes involved in the instability of a slope. **(10)**

(c) Fig. 6 shows the cross-section of an earth slope in homogeneous clay soil. The figure also shows an arbitrary failure surface, its center and five slices. Calculate the factor of safety, using Ordinary Method of Slices. Given, unit weight of soil = 17.5 kN/m^3 and q_u = 60 kPa. For homogenous soil and Ordinary Method of Slices. Factor of Safety (Fs) is given by: **(13+2=15)**

$$Fs = \frac{\sum_{n=1}^{n=p}[c\Delta L_n + Wn \cos \alpha_n \tan \emptyset]}{\sum_{n=1}^{n=p} W_n \sin \alpha_n}$$

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Contd ..... Q. No. 7(c)

What will be variation in factor of safety (*Fs*) value if Bishop's Simplified method of slices is used for slope stability analysis?

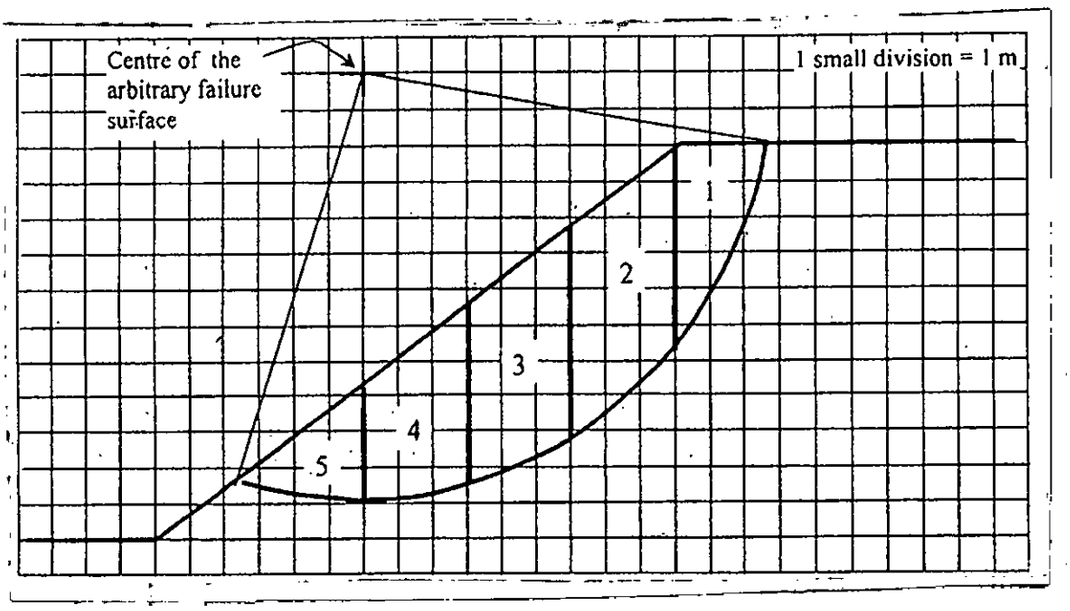

Fig. 6 For Q. No. 7(c):

8. (a) A concrete closed-ended pipe pile, 0.4 m in diameter, is driven 20 m into the soil profile shown in **Fig. 7**. Groundwater table is at 2 m below the surface, but you can assume that it will rise to the surface. A factor of safety, F_s, of 2 is required. Determine the allowable load: (i) compressional for considering negative skin friction if it appears to exist, (ii) compressional but neglect the situation of existing negative skin friction, and (iii) tensile (i.e., uplift capacity) with $F_s = 2$. **(20)**

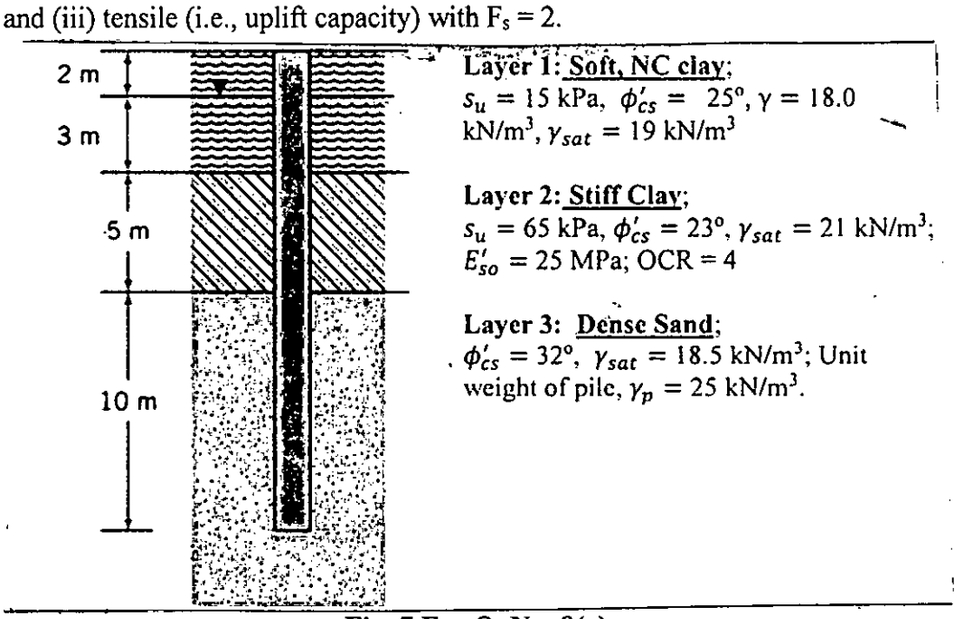

Fig. 7 For Q. No. 8(a)

(b) State and explain two advantages and two disadvantages of using driven piles instead of cast-in-situ piles at a site. **(15)**

L-4/T-1/CE **Date : 25/03/2024**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-1 B. Sc. Engineering Examinations 2021-2022

Sub : **CE 451** (Transportation Engineering II: Pavement Design & Railway Engineering)

Full Marks : 280 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.

Assume reasonable values for missing data (if any).

1. (a) Discuss the ways to modify conventional earth roads to Engineered low-cost roads. Compare between Dense bituminous carpeting and Single bituminous surface treatment (SBST) with Cap seal. Draw an illustrated diagram of cross-section of a typical Hering Bone Brick (HBB) pavement as used in Bangladesh. **(10+8+5)**

   (b) Explain use, construction process, materials required and load bearing mechanisms of water bound Macadam (WBM), Dry bound Macadam (DBM) and Penetration Macadam. Discuss the uses of different types of rollers (at least 3 types) and special trucks (at least 3 types) in asphalt pavement and underlying earth embankment construction. **$(12+11\frac{2}{3})$**

2. (a) Explain quality control and quality verification tests, test frequency and variation tolerance for earth embankment and pavement granular aggregate base/subbase layer construction. Explain pavement maintenance management system with a flow chart followed by noting of the salient tasks of the system. **(14+9)**

   (b) Explain the quality control plan for asphalt concrete and cement concrete paving mix. Make a comparison among alligator, shrinking, reflection and longitudinal cracks of flexible pavement. Draw illustrated cross sections of the following: (i) Doweled isolation joint (ii) Doweled contraction joint and (iii) Tied contraction joint. **$(11+6+6\frac{2}{3})$**

3. (a) **(3+3+3+3+3+3)**

   (i) Define and broadly classify pavement.

   (ii) On which respect the moisture is 'enemy for bituminous pavement and friend for concrete pavement'.

   (iii) Draw a typical layer system for perpetual pavement.

   (iv) In your opinion write down main considerations for perpetual pavement.

   (v) Briefly state the significance of polymer-modified binder (PMB) use in Bangladesh.

Contd P/2

CE 451

Contd...Q. No. 2

(b) **(3+3+3+3+3)**

(i) State the common modes of distress for bituminous and concrete pavement in Bangladesh.

(ii) Differentiate between flexible and rigid pavements w.r.t. six considerations.

(iii) What type of pavement is suitable for Bangladesh and Why?

(iv) Briefly show the sequences of pavement failure under submerged conditions.

(v) What traffic management measures should be taken during the submergence period?

(c) An existing 4-lane National highway constructed on an embankment requires full reconstruction. A number of trial pits were undertaken, and the CBR of the subgrade beneath the existing road was found to be 3%. A 24 hour classified traffic count was carried out on a typical weekday and showed only heavy vehicles as follows: **($8\frac{2}{3}$)**

Vehicle Categories	Base year Two-way Flow / day
Heavy truck	50
Medium truck	300
Light truck	550
Large bus	200

Determine the pavement layer thicknesses by using the RHD flexible pavement design guide method. Consider an annual traffic growth rate of 8% and a design period of 20 years. Use Base type I.

Necessary information is given in Table 1 to 3.

(d) What is a standard axle load? A truck on an intercity road applies 24kip and 16kip loads to the rear and front axles. Using the 4th power approximation, determine the total equivalent damage caused by the one-pass movement of this truck in terms of ESALs. **(5)**

4. (a) **(2+2+2+3+3)**

(i) Mention major findings of the AASHTO Road Test.

(ii) Why is the ditto copy of the AASHTO method of pavement design not appropriate for Bangladesh?

(iii) Write down the functions of Dowel bars.

(iv) Draw a typical joint detail of rigid pavement, showing the sealant reservoir and backer rod.

(v) List the different methods of flexible and rigid pavement design.

(b) **(2+2+2+3+3)**

(i) Schematically show the 'Contraction Joint' and 'Construction Joint'.

(ii) Mention the main benefits of continuously reinforced concrete pavement (CRCP)

(iii) Reasons for using joints in rigid pavement.

(iv) Write down the composition of ingredients for Fog-seal, Slurry-seal, and Micro-seal.

(v) State the steps involved with the patchwork of bituminous pavements.

Contd P/3

CE 451

Contd...Q. No. 4

(c) Design reinforcement for a rigid pavement with the following data and draw reinforcement details: **(10)**

Thickness of rigid pavement, t =	9	inch
No of lanes =	2	
Width of pavement, w =	22	ft
Spacing of transverse joint =	44	ft (Contraction Joint @ 22ft)
Allowable strength of:		
Shrinkage steel(bar-mat) =	45000	psi
Tie bars =	35000	psi
Bond =	350	psi

(d) Design a concrete pavement using the PCA method for the following specified conditions. Provide one trial and include your comments on the trial thickness. Provide your solution in the worksheet provided at the end of the question paper. **($12\frac{2}{3}$)**

Truck Axle Load Distributions

Axle Load Groups (kip)	Number of Axles, N	Axle Load Groups (kip)	Number of Axles, N
Single Axles		**Tandem Axle**	
22	6,500	32	1,25,000
24	14,000	36	2,50,000

Modulus of Subgrade Reaction, k:		100	pci
Modulus of Rupture, MR	:	550	psi
Load Safety Factor	:	1.2	
Doweled joints	:	Yes	
Concrete Shoulder	:	No	
Subbase	:	No	

Necessary information is given in Table 4 to 5 and Figure 1 & 2.

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE** questions.

5. (a) Explain the advantages of Railway over Roadway. Calculate the maximum permissible load that a BG locomotive with 3 pairs of driving wheels bearing an axle load of 22 t each can pull on a straight level track at a speed of 80 km/h. Assume the coefficient of friction to be 0.2. **(15)**

(b) Explain the factors affecting the choice of a gauge in a county. What are the problems caused by non-uniformity of gauges in a county? Write the functions of rails. **(15)**

(c) Show with a neat sketch different component of Permanent Way. Explain the advantages of flat-footed rails. What are the factors to be considered for deciding the weight of rails and its sections? **($16\frac{2}{3}$)**

Contd P/4

CE 451

6. (a) Write the requirements of an ideal fastening connecting rail and sleeper. Draw a labeled neat sketch of a crossing station with a single main line and two loop lines. **(15)**

(b) Write the requirements of an ideal rail sleeper. Draw a labeled neat sketch of a crossing station with double main lines and a common loop line. **(15)**

(c) Write the requirements of good ballast. Draw a labeled neat sketch of a crossing station with double main lines and two loop lines. **$(16\frac{2}{3})$**

7. (a) Classify aggregates based on geographical origin. Discuss the importance of determining following aggregate properties: (i) Coarse Aggregate angularity; (ii) Fine Aggregate Angularity; (iii) Flat and Elongated Particle; and (iv) Clay Content. Also, explain the following statements with examples – "It is important to recognize that some aggregates appear to have a greater affinity for water than for asphalt cement. **(20)**

(b) Discuss the advantages and problems of excessive mineral filter uses in asphalt concrete mixtures. Also, mention the RHD specifications for coarse and mineral filler for bituminous mix suitable for roads in Bangladesh. **$(16\frac{2}{3})$**

(c) The specific gravities and weight proportions for aggregate and bitumen shown in the table for the preparation of Marshall mix design. The volume and weight of one Marshall specimen was found to be 475 cc and 1100 gm. Assuming absorption of bitumen in aggregate is zero, find percentage of void in the total mix (V_v), percent bitumen content in the mix (V_b), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB). **(10)**

Item	Aggregate 1	Aggregate 2	Aggregate 3	Aggregate 4	Bitumen
Weight (gm)	825	1200	325	150	100
Specific Gravity	2.63	2.51	2.46	2.43	1.05

8. (a) Discuss the advantage of cutbacks compared to emulsions. State the properties of HFMS-2h and SS-1h type asphalt binder. Differentiate slow and rapid-curing cutback asphalts. **$(11\frac{2}{3})$**

(b) Discuss the effect of air voids content in asphalt paving mixtures. Also, state the main difference between Marshall and HVEEM method of mix design with regard to: (i) compaction of specimens, (ii) design criteria, and (iii) tests of specimens. **(15)**

(c) Calculate the Approximate Bitumen Ration (ABR) i.e. the starting asphalt content in the test series of HVEEM mix design procedure for Medium Curing cutback asphalt [MC-3000]. The necessary data are provided below: **(20)**

Surface area of aggregates	34.8 ft^2/lb
Specific gravity of fine aggregates	2.62
Specific gravity of coarse aggregates	2.72
Weighted average Specific gravity of fine and coarse aggregates	2.66
% of fine aggregate	55
% of coarse aggregate	45
C.K.E of two fine aggregate specimens	7.4, 7.2
% Oil retained of two coarse aggregate specimens	2.8, 2.8

For Q 3(c)

Table 1: Improved Sub-grade Requirements

CBR Required	Compacted thickness of additional layer to provide required CBR				
	CBR of underlying layer				
	<2%	2%	3%	4%	5%
5%	Sub-grade material should be removed	450mm	300mm	250mm	200mm

Table 2: Vehicle Equivalent Factors

Vehicle Category	Equivalence Factor
Large Truck (dual axle)	4.8
Medium Truck (Single axle)	4.62
Small Truck	1.0
Large Bus	1.0
Mini Bus	0.5

Table 3: Thickness Design Table for Flexible Pavements (RHD design guide method)

mm	Surfacing (mm)		Roadbases (mm)* (Select one type)			Sub-bases (mm)** Subgrade CBR %		
Traffic ESA (mill)	Asphalt Wearing Course	Asphalt Base-Course	Cement-bound Granular	Granular Base Type I	Granular Base Type II	5	8 - 25	> 25
60 - 80	40	155	Refer to BRRL for design advice	N/A	N/A	300	150	0
40 - 60		140						
30 - 40		125		250	300	250		
25 - 30		110						
17 - 25		105				200		
15 - 17		95						
11 - 15		90						
9 - 11		80		200	250			
7 - 9		70						
6 - 7		65						
5 - 6		60						
4 - 5		55						
3 - 4		45		175	200	175		
< 3		35		150	175	150		

* CBR of granular base type I is min. 80%
* CBR of granular base type II is min 50%
** CBR of sub-base material is 25%

N/A = not applicable

For Q 4(d)

Table 4: Equivalent Stress — No Concrete Shoulder (Single Axle/Tandem Axle)

Slab thickness, in.	*k* of subgrade-subbase, pci						
	50	100	150	200	300	500	700
4	825/679	726/585	671/542	634/516	584/486	523/457	484/443
4.5	699/586	616/500	571/460	540/435	498/406	448/378	417/363
5	602/516	531/436	493/399	467/376	432/349	390/321	363/307
5.5	526/461	464/387	431/353	409/331	379/305	343/278	320/264
6	465/416	411/348	382/316	362/296	336/271	304/246	285/232
6.5	417/380	367/317	341/286	324/267	300/244	273/220	256/207
7	375/349	331/290	307/262	292/244	271/222	246/199	231/186
7.5	340/323	300/268	279/241	265/224	246/203	224/181	210/169
8	311/300	274/249	255/223	242/208	225/188	205/167	192/155
8.5	285/281	252/232	234/208	222/193	206/174	188/154	177/143
9	264/264	232/218	216/195	205/181	190/163	174/144	163/133
9.5	245/248	215/205	200/183	190/170	176/153	161/134	151/124
10	228/235	200/193	186/173	177/160	164/144	150/126	141/117
10.5	213/222	187/183	174/164	165/151	153/136	140/119	132/110
11	200/211	175/174	163/155	154/143	144/129	131/113	123/104
11.5	188/201	165/165	153/148	145/136	135/122	123/107	116/98
12	177/192	155/158	144/141	137/130	127/116	116/102	109/93
12.5	168/183	147/151	136/135	129/124	120/111	109/97	103/89
13	159/176	139/144	129/129	122/119	113/106	103/93	97/85
13.5	152/168	132/138	122/123	116/114	107/102	98/89	92/81
14	144/162	125/133	116/118	110/109	102/98	93/85	88/78

Table 5: Erosion Factors - Doweled Joints, No Concrete Shoulder (Single/Tandem Axle)

Slab thickness,	*k* of subgrade-subbase, pci					
	50	100	200	300	500	700
4	3.74/3.83	3.73/3.79	3.72/3.75	3.71/3.73	3.70/3.70	3.68/3.67
4.5	3.59/3.70	3.57/3.65	3.56/3.61	3.55/3.58	3.54/3.55	3.52/3.53
5	3.45/3.58	3.43/3.52	3.42/3.48	3.41/3.45	3.40/3.42	3.38/3.40
5.5	3.33/3.47	3.31/3.41	3.29/3.36	3.28/3.33	3.27/3.30	3.26/3.28
6	3.22/3.38	3.19/3.31	3.18/3.26	3.17/3.23	3.15/320	3.14/3.17
6.5	3.11/3.29	3.09/3.22	3.07/3.16	3.06/3.13	3.05/3.10	3.03/3.07
7	3.02/3.21	2.99/3.14	2.97/3.08	2.96/3.05	2.95/3.01	2.94/2.98
7.5	2.93/3.14	2.91/3.06	2.88/3.00	2.87/2.97	2.86/2.93	2.84/2.90
8	2.85/3.07	282/299	2.80/2.93	2.79/2.89	2.77/2.85	2.76/2.82
8.5	2.77/3.01	2.74/2.93	2.72/2.86	2.71/2.82	2.69/2.78	2.68/275
9	2.70/2.96	2.67/287	2.65/2.80	2.63/2.76	2.62/2 71	2.61/2.68
9.5	2.63/2.90	2.60/2.81	2.58/2.74	2.56/2.70	2.55/2.65	2.54/2.62
10	2.56/2.85	2.54/2.76	2.51/2.68	2.50/2.64	2.48/2.59	2.47/256
10.5	2.50/2.81	2.47/2.71	2.45/2.63	2.44/2.59	2.42/2.54	2.41/2.51
11	2.44/2.76	2.42/2.67	2.39/2.58	2.38/2.54	2.36/2.49	2.35/2.45
11.5	2.38/2 72	2.36/2.62	2.33/2.54	2.32/2.49	2.30/2.44	2.29/2.40
12	233/2.68	2.30/2 58	2.28/2.49	2.26/2.44	2.25/2.39	2.23/2.36
12.5	2.28/2.64	2.25/2.54	2.23/2.45	2.21/2.40	2.19/2.35	2.18/2.31
13	2.23/2.61	2.20/2.50	2.18/2.41	2.16/2.36	2.14/230	2.13/2 27
13.5	2.18/2.57	2.15/2.47	2.13/2.37	2.11/2.32	2.09/2.26	2.08/2 23
14	2.13/2.54	2.11/2.43	2.08/2.34	2.07/2.29	2.05/2.23	2.03/2.19

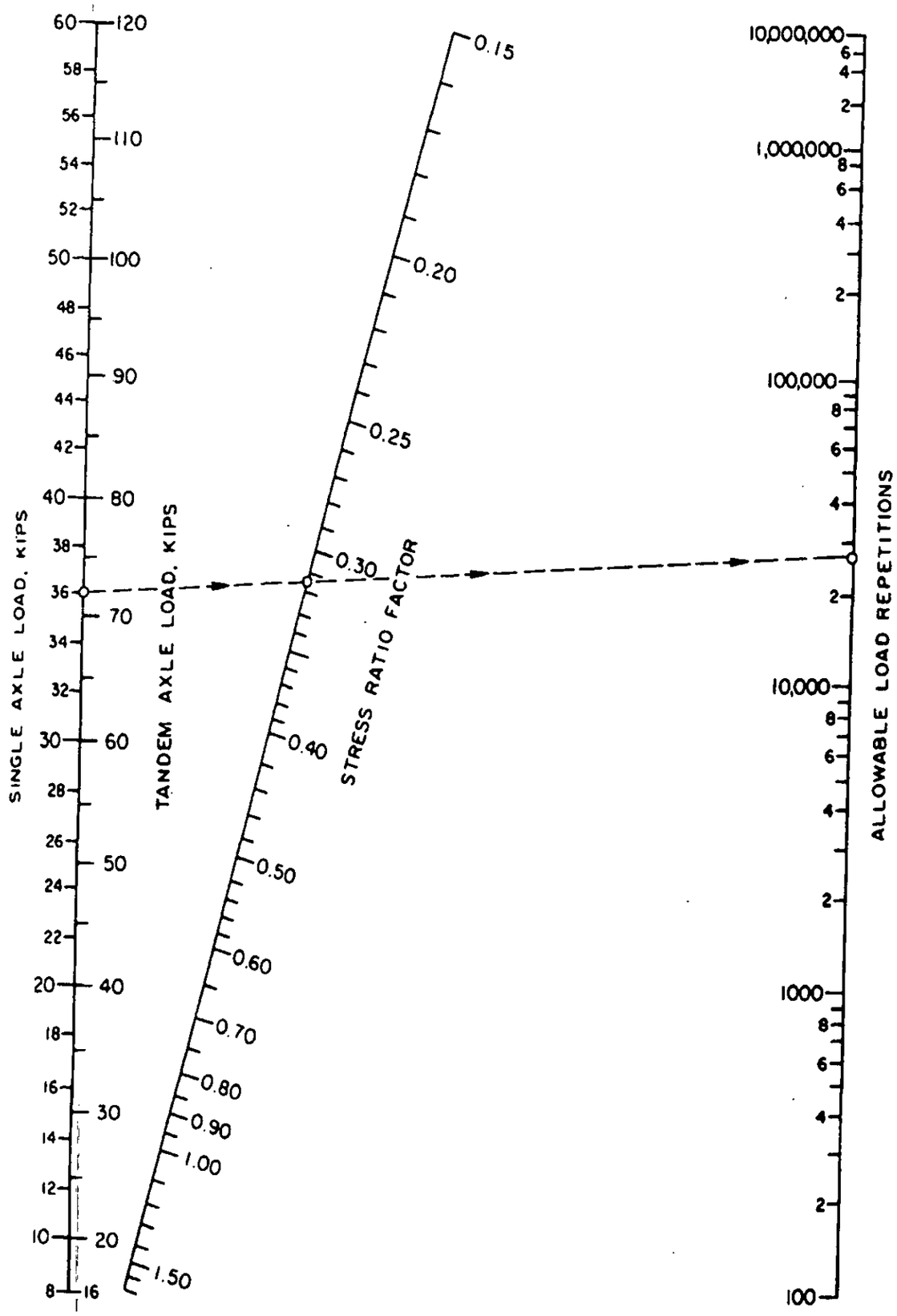

Figure 1: Fatigue analysis—allowable load repetitions based on stress ratio factor (with and without concrete shoulder).

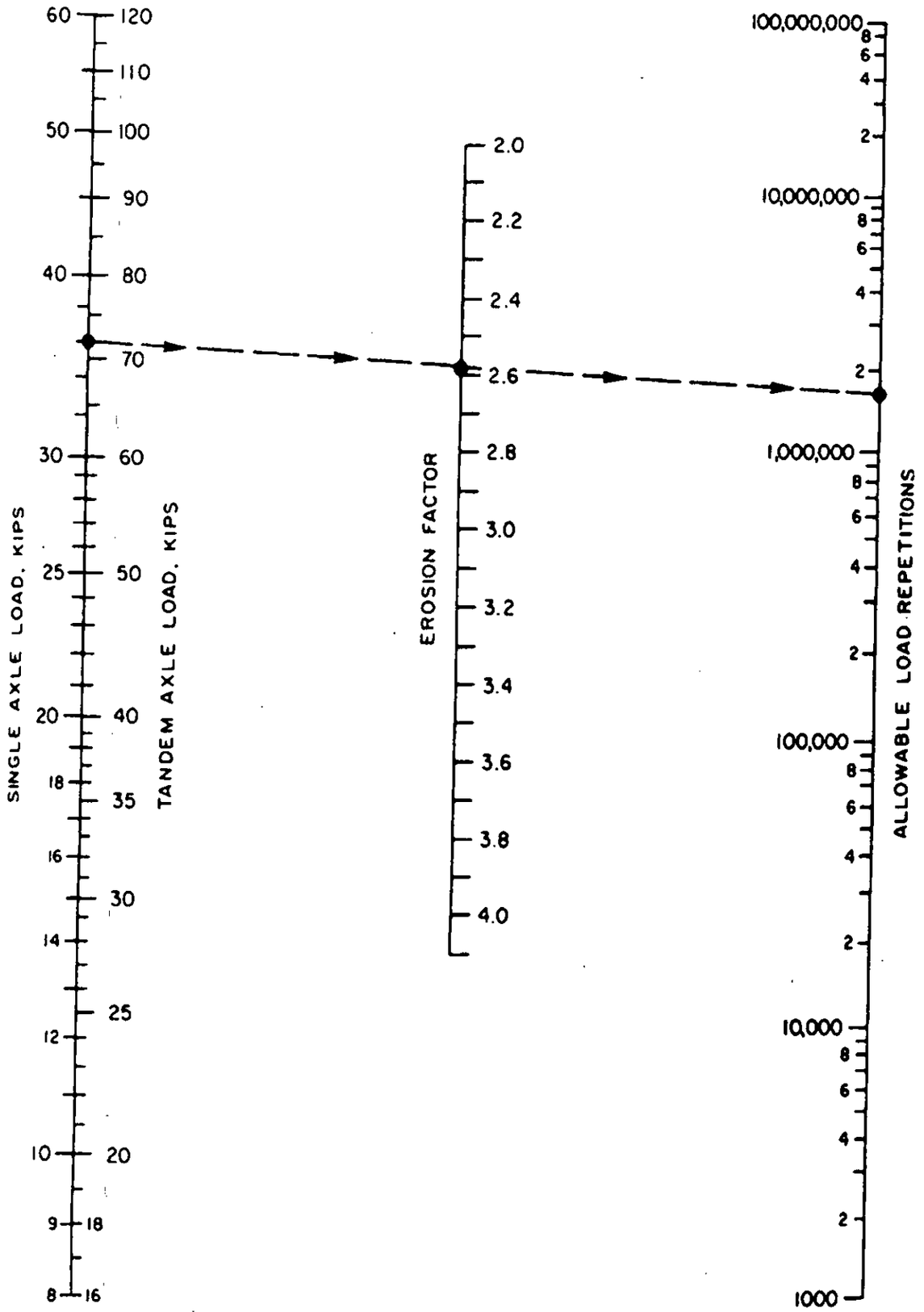

Figure 2: Erosion analysis—allowable load repetitions based on erosion factor (without concrete shoulder).

Worksheet

Calculation of Pavement Thickness

Project _____

Trial thickness _____ in
Subbase-subgrade, k _____ pci
Modulus of Rupture, MR _____ psi
Load safety factor, LSF _____

Doweled joints yes ____ no ____
Concrete shoulder yes ____ no ____

Design Period _____ years

Axle Load, kips	Multiplied by LSF	Expected repetitions	Fatigue analysis		Erosion Analysis	
			Allowable repetitions	Fatigue Percent	Allowable repetitions	Damage Percent
1	2	3	4	5	6	7

8. Equivalent stress _____
9. Stress ratio factor _____
10. Erosion factor _____

Single Axles

11. Equivalent stress _____
12. Stress ratio factor _____
13. Erosion factor _____

Tandem Axles

			Total		Total	

HVEEM Design Charts:

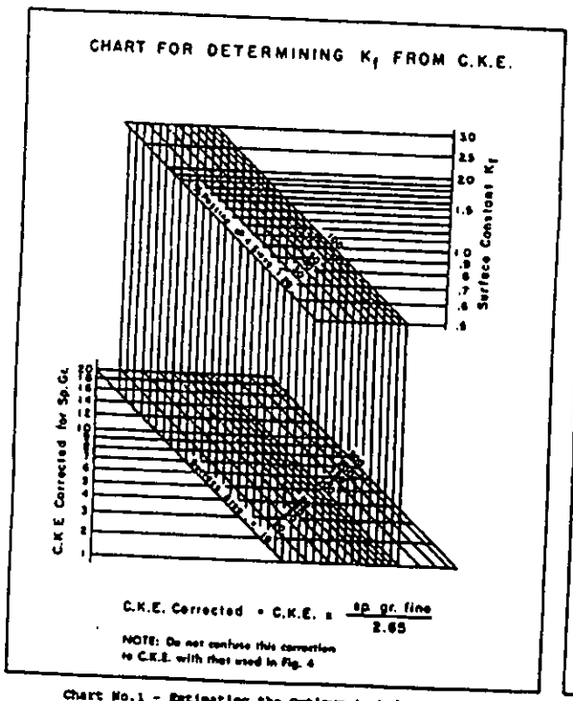

Chart No.1 - Estimating the Optimum Asphalt Content.
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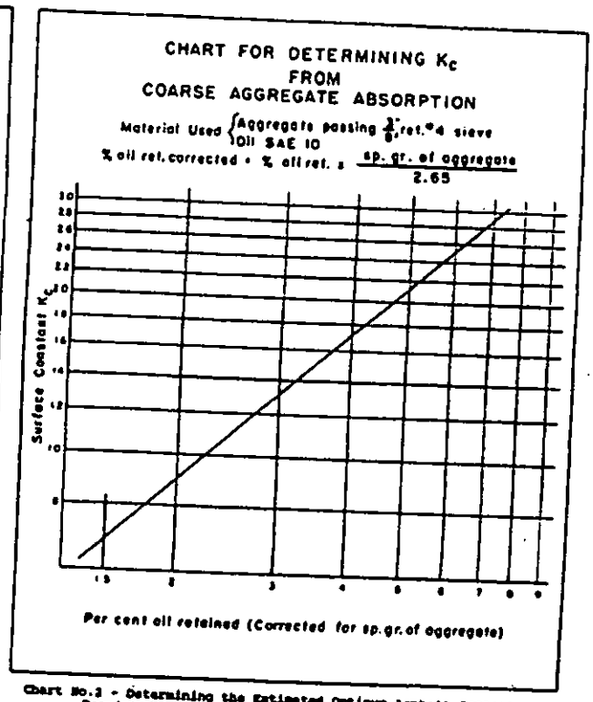

Chart No.2 - Determining the Estimated Optimum Asphalt Content.
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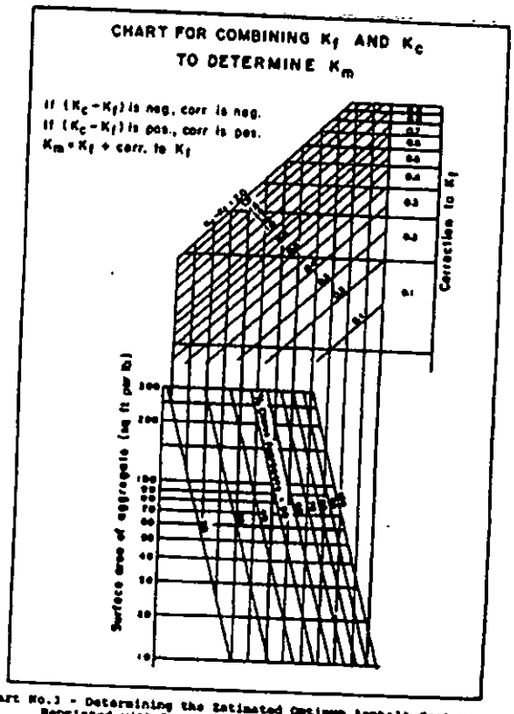

Chart No.3 - Determining the Estimated Optimum Asphalt Content.
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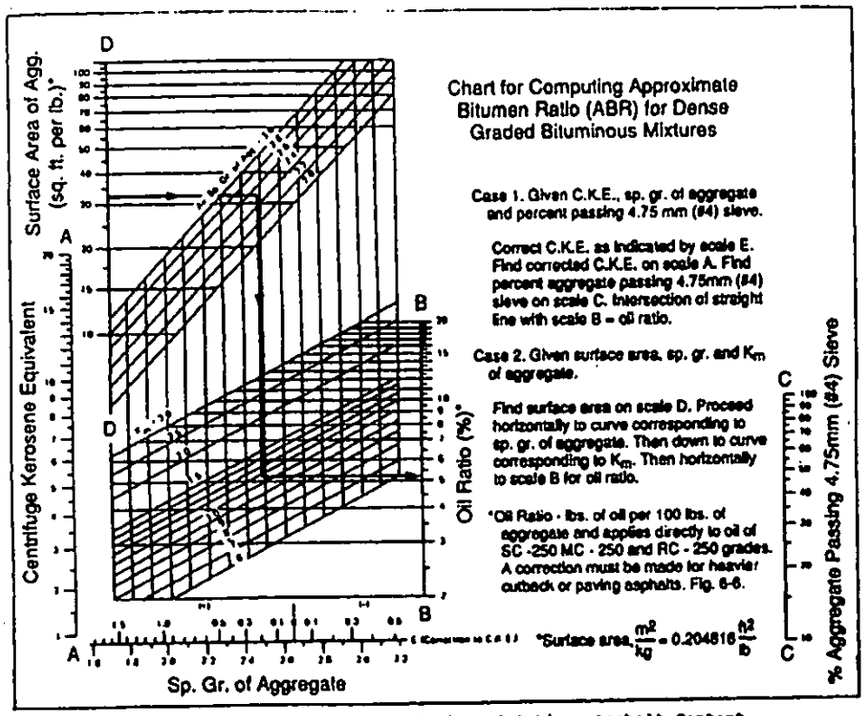

Chart No.4 - Determining the Estimated Optimum Asphalt Content.
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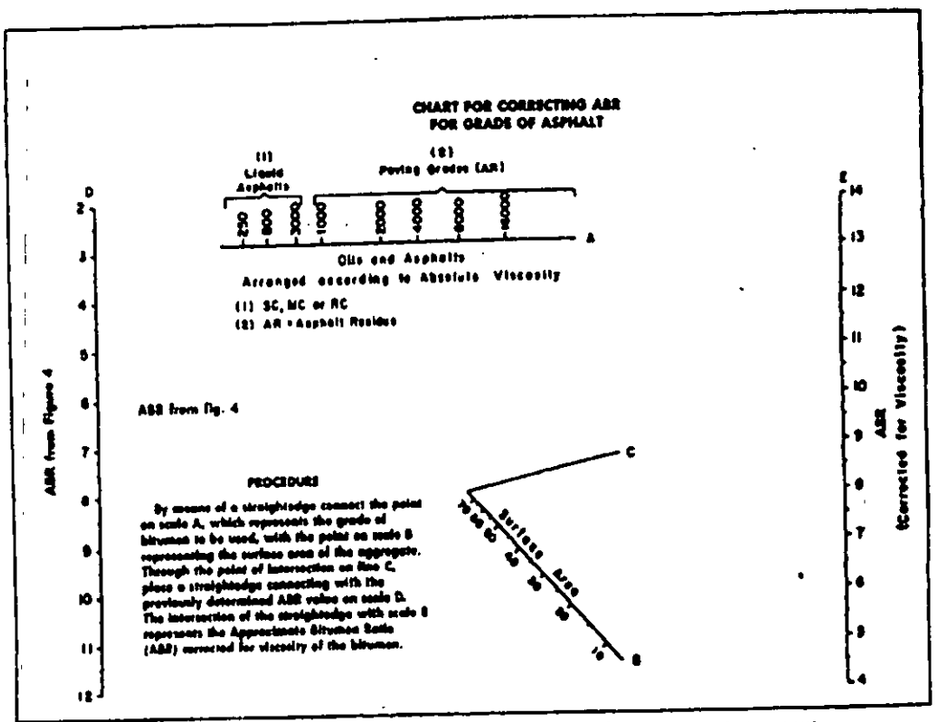

Chart No.5 - Determining the Estimated Optimum Asphalt Content.
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L-4/T-1/CE Date: 25/5/24 ~~28/04/2024~~

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-1 B. Sc. Engineering Examinations 2022-2023

Sub: **WRE 451** (Hydrology, Irrigation and Flood Management)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks.

Assume reasonable values for any missing data.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) How does irrigation contribute to agricultural practices, especially in regions with insufficient natural rainfall? **(6)**

(b) Suppose you are producing the same crop in two different climatic zones of Bangladesh. One in the southeastern region and the other in the northeastern part—would you anticipate variations in the crop's consumptive water use during its base period in these locations? Explain the reasons behind any expected differences? **(8)**

(c) Describe the concepts of duty and delta within the context of water requirements for crops, and explain how they influence irrigation practices and the planning of water resources for agricultural purposes? **(7)**

(d) The farmer has chosen to implement a border irrigation system for a rectangular agricultural field, spanning 10 hectares with dimensions of 500 meters in length and 200 meters in width. This field, designated for rice cultivation, features a consistent slope of 0.5% from the water inlet to the far end, facilitating the gravity-driven flow essential for border irrigation. With a roughness coefficient of 0.12, the field's surface conditions and accounted for in the irrigation design. Additionally, the empirical parameter of the Kostiakov infiltration equation parameters have been determined as k = 0.033 m/ha and a = 0.03, with a required infiltration depth of 3 inch. Based on these specified characteristics, the task is to design the border strips, ensuring efficient water distribution that meets the crop's irrigation needs while optimizing the use of available resources. **(14)**

2. (a) Provide a brief explanation of one of the irrigation projects in Bangladesh, outlining its objectives. **(6)**

(b) Given a scenario where you have a diverse agricultural farm that includes various crops with different water requirements, situated on a sloped terrain with sandy loam soil. Suppose the region is experiencing moderate wind conditions. What type of irrigation method do you choose for this scenario and how would you justify your decision. **(7)**

Contd P/2

WRE 451/CE

Contd... Q. No. 2

(c) You are asked to plan for an irrigation project for a command area beside Dharla river at Kurigram district. The topographic survey of the command area shows slight undulation in the land elevations. You are suggested to divert the river water to the main irrigation canal using a barrage. Sketch the qualitative canal network system for this command area. **(6)**

(d) Determine the volume of water required to be diverted from the head works to the irrigation field (5000 ha) using the following data. Assume 80% as the effective precipitation to take care of the consumptive use of the crop. Also assume 50% efficiency of water application in the field and 75% as the conveyance efficiency. **(16)**

Month	Temp °F	Sunshine hour	Rainfall (mm)	Crop Factor (k)
June	70.8	9.9	75	0.8
July	74.4	10.2	108	0.85
August	72.8	9.6	130	0.85
September	71.6	8.4	115	0.85
October	69.3	7.86	105	0.65
November	55.2	7.25	25	0.65
December	47.1	6.42	0	0.6
January	48.4	8.62	0	0.6
February	53.9	9.95	0	0.65
March	60	8.84	0	0.7
April	62.5	8.86	0	0.7
May	67.4	9.84	0	0.75

3. (a) How the Water Policy 1999 is different from Bangladesh Water Act 2013? **(7)**

(b) How does the soil influence plant growth and development? What strategies can be employed to optimize these soil-plant relationships for enhanced agricultural productivity? **(7)**

(c) Imagine you're a renowned agricultural consultant tasked with enhancing the water management strategies of a vast and fertile farmland. The farm, known for its cash crops and innovative practices, faces a new challenge: optimizing its irrigation to match the unique characteristics of its soil, ensuring every drop of water contributes to crop growth. **(13)**

Contd P/3

WRE 451/CE

Contd... Q. No. 3(c)

The plants' roots stretch deep, reaching down 1.8 meters into the earth. The land, although fertile, holds a modest existing moisture content of 8%. The soil, dense and rich, carries a dry weight of 1450 kg/m^3.650 m^3 of water gently applied to the soil to nurturing its land where 10% of water is lost due to deep percolation and evaporation. The decision is made to irrigate the area of 1000 m^2 of land. Determine the field capacity of a soil as well as recommend optimal irrigation depth and frequency to support optimum crop yield.

(d) Explain the mechanism of peak flow attenuation in flood control or management, and assess its suitability as a flood mitigation practice for Bangladesh? **(8)**

4. (a) Explain how drainage enhances the effectiveness of irrigation systems? **(5)**

(b) Imagine your village is situated close to Sunamganj, a region that frequently experiences flooding each year. Could you identify the specific type of flooding that occurs in this area and propose suitable flood mitigation strategies for your village? Elaborate on your chosen approach and its effectiveness in addressing the unique challenges presented by the flood conditions. **(12)**

(c) Estimate the leaching requirement when the electrical conductivity of saturated extract soil is 10 mmho/cm at 25% reduction in the yield of a crop. The electrical conductivity of irrigation water is 1.2 mmho/cm. **(6)**

(d) At a certain place in Bangladesh, the transplantation of rice takes 16 days, and the total depth of water required by the crop is 60 cm on the field. During this transplantation period of 16 days, rain starts falling and about 10 cm of rain is being utilized to fulfill the rice demand. Find the duty of the irrigation water required for rice during transplanting period. **(12)**

(i) Assuming 25% losses of water in the water course, find the duty of water at the head of the watercourse.

(ii) Find the duty of water at the head of the distributary, assuming 15% losses from the distributary head to the watercourse head.

(iii) Describe the various types of water losses encountered in irrigation canal systems.

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SECTION – B

There are **FOUR** questions in this section. Answer any **THREE** questions.

5. (a) A storm with 10 cm precipitation produced a direct runoff of 5.8 cm. Given the time distribution of the storm as below, estimate the ϕ index of the storm. **(15)**

Time (h)	0	1	2	3	4	5	6	7	8
Incremental rainfall in each hour (cm)	0	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5

(b) Rainfall of magnitude 3.8 cm and 2.8 cm occurring on two consecutive 4-h durations on a catchment of area 27 km^2 produced the following hydrograph at the outlet of the catchment. Estimate the rainfall excess and infiltration volume. **(15)**

Time (h)	-6	0	6	12	18	24	30	36	42	48	54	60
Observed flow (m^3/s)	6	5	13	26	21	16	12	9	7	5	5	4.5

(c) What are the uses and limitations of unit hydrographs? **(5)**

6. (a) Observed values of inflow and outflow hydrographs at the ends of a reach in a river are given below. Determine the best values of K and x for use in the Muskingum method of flood routing. **(25)**

time (h)	0	6	12	18	24	30	36	42	48	54	60	66
inflow (m^3/s)	20	80	210	240	215	170	130	90	60	40	28	16
outflow (m^3/s)	20	20	50	150	200	210	185	155	120	85	55	23

(b) Ordinates of a 4-h unit hydrograph are given. Using this derive the ordinates of a 2-h unit hydrograph for the same catchment. **(10)**

Time (h)	0	4	8	12	16	20	24	28	32	36	40	44
Ordinates of a 4-h UH (m^3/s)	0	20	80	130	150	130	90	52	27	15	5	0

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7. (a) Compare and contrast between perennial stream, intermittent stream and ephemeral stream. **(5)**

(b) Annual maximum recorded floods in the river Padma at point X, for the period 1951 to 1974 is given below. Verify whether the Gumbel extreme value distribution fit the recorded values. Estimate the flood discharge with recurrence interval of (i) 100 years and (ii) 150 years by graphical extrapolation. Use Semi-log paper if necessary. **(30)**

Year	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
Max flood (m^3/s)	2947	3521	2399	4124	3496	2947	5060	4903	3757	4798	4290	4652

Year	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Max flood (m^3/s)	5050	6900	4366	3380	7826	3320	6599	3700	4175	2988	2709	3873

8. (a) Briefly describe the concept of Thiessen Polygon with an appropriate diagram. **(5)**

(b) Briefly describe the use of telemetry in hydrologic data acquisition. **(10)**

(c) The following table shows the observed annual rainfall and the corresponding annual runoff for a small catchment. Develop the rainfall-runoff correlation equation for this catchment and find the correlation coefficient. What annual runoff can be expected from this catchment for an annual rainfall of 100 cm? **(20)**

year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
annual rainfall (cm)	90.5	111	38.7	129.5	145.5	99.8	147.6	50.9	120.2	90.3	65.2	75.9
annual runoff (cm)	30.1	50.2	5.3	61.5	74.8	39.9	64.7	6.5	46.1	36.2	24.6	20.0

Supplement Equations if Required.

1. $\Delta = \frac{8.64\,B}{D}$
2. $\eta_d = \left(1 - \frac{d}{D}\right)$
3. $CIR = C_u - R_e$
4. $C_u = \frac{k.p}{40}[1.8t + 32]$
5. $E_p = 0.459.\ R.C_t.C_w.C_h.C_s.C_e$
6. $E_t = \frac{A.H_n + E_a\gamma}{A+\gamma}$
7. $V = \left[\frac{Qf^2}{140}\right]^{1/6}$
8. $D_{iw} = D_c + D_d$
9. $C_t = 0.393 + 0.02796\,T_c + 0.0001189T_c^2$
10. $C_w = 0.708 + 0.0034W - 0.0000038W^2$
11. $C_h = 1.250 - 0.0087H + 0.75 \times 10^4 H^2 - 0.85 \times 10^{-8} H^4$
12. $C_s = 0.542 + 0.008S - 0.78 \times 10^{-4} S^2 + 0.62 \times 10^{-6} S^3$
13. $H_n = H_c(1-r)\left(a + b\frac{n}{N}\right) - \sigma T_a^4\left(0.56 - 0.092\sqrt{e_a}\right) \times \left(0.10 + 0.90\frac{n}{N}\right)$
14. $q_{min} = (5.95 \times 10^{-6}) \times \frac{L \times S_0^{0.5}}{n}$
15. $q_{apl} = CU_q \frac{L^{1.0562} \times n^{0.1094} \times k^{1.225} \times a^{3.832}}{S^{0.09} \times D_{req}^{0.823}}$
16. $T_{apl} = CU_T \frac{L^{1.1} \times n^{0.0093} \times S_0^{0.0203} \times k^{0.387} \times D_{req}^{0.952}}{q_{apl}^{1.0885} \times a^{0.75}}$
17. $S = \frac{f^{5/3}}{3340Q^{1/6}}$
18. $SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$
19. $SP = \frac{Na^+}{Na^+ + Ca^{++} + Mg^{++} + K^+} \times 100$
20. $LR = {}^{D_d}/_{D_{iw}} = {}^{EC_{iw}}/_{EC_d}$
21. $D_{iw} = [EC_d/(EC_d - EC_{iw})] \times D_c$
22. $C_e = 0.97 + 0.00984\,E$