P.E. Civil Exam Review:

Construction Scheduling and Estimating

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ASCE | KNOWLEDGE & LEARNING

Project Management

What is a Project?

- Project
  - unique, one-time operational activity or effort
- Examples
  - constructing houses, factories, shopping malls, athletic stadiums or arenas
  - developing military weapons systems, aircrafts, new ships
  - launching satellite systems
  - constructing oil pipelines
  - developing and implementing new computer systems
  - planning concert, football games, or basketball tournaments
  - introducing new products into market

- Objective
- Scope
- Contract requirements
- Schedules
- Resources
- Personnel
- Control
- Risk and problem analysis

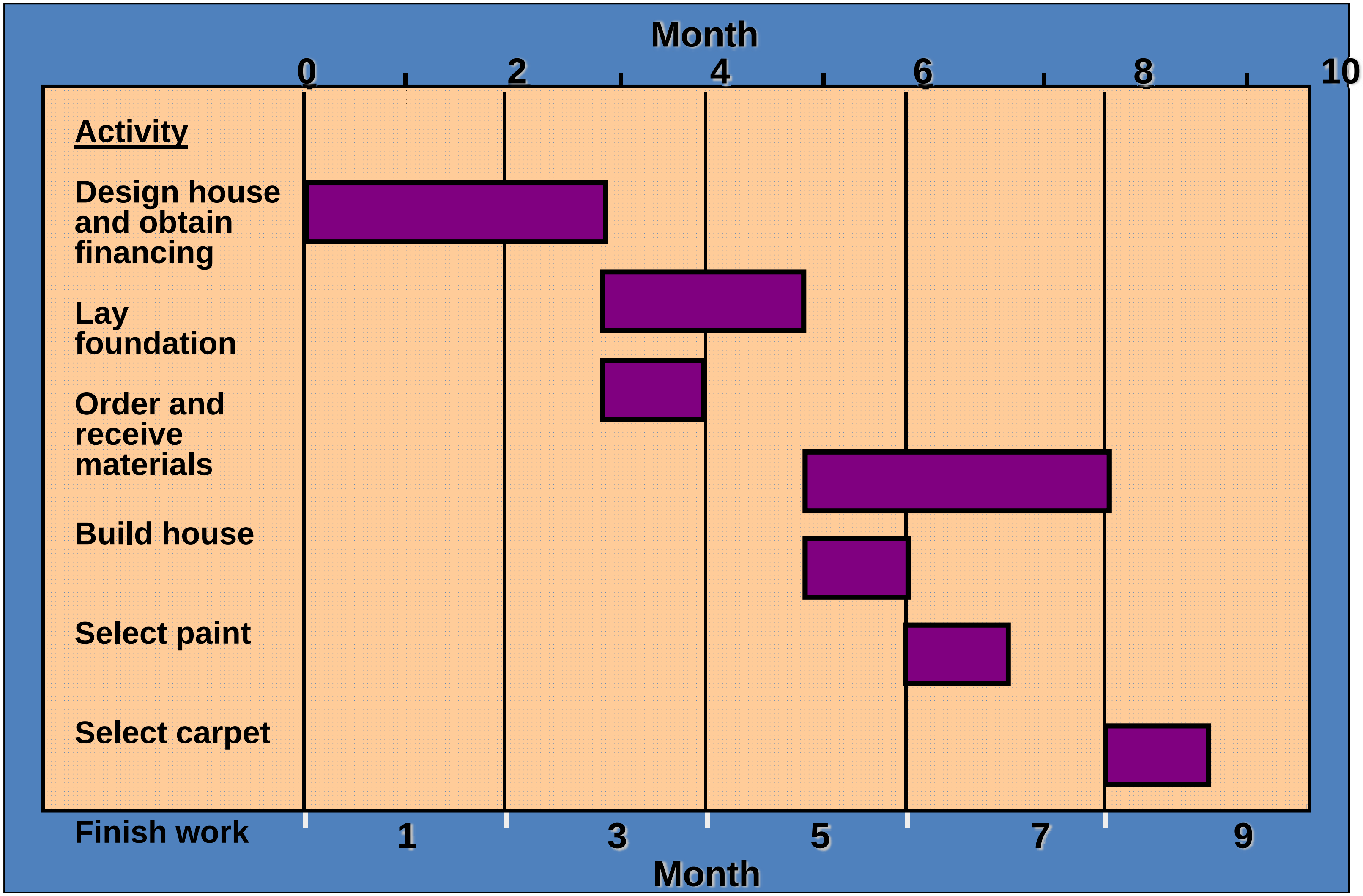
Project Scheduling

- Steps
  - Define activities
  - Sequence activities
  - Estimate time
  - Develop schedule
- Techniques
  - Gantt chart
  - CPM
  - PERT
  - Microsoft Project

Gantt Chart

- Graph or bar chart with a bar for each project activity that shows passage of time
- Provides visual display of project schedule
- Slack
  - amount of time an activity can be delayed without delaying the project

Example of Gantt Chart

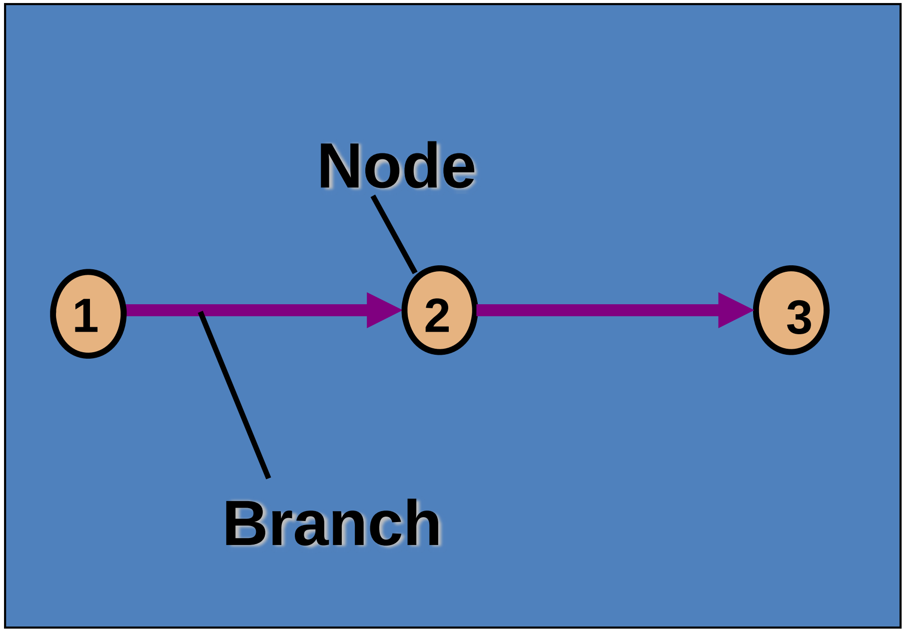


CPM/PERT

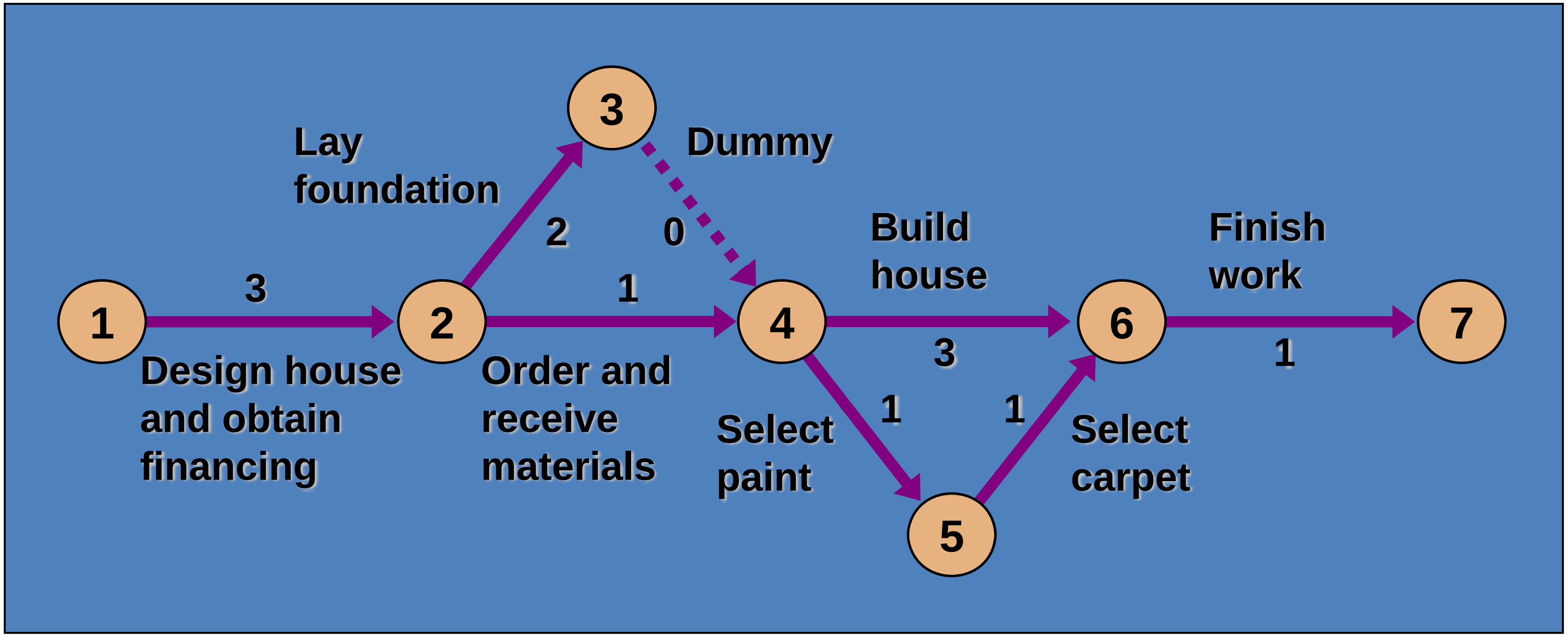
- Critical Path Method (CPM)
  - DuPont & Remington-Rand (1956)
  - Deterministic task times
  - Activity-on-node network construction
- Project Evaluation and Review Technique (PERT)
  - US Navy, Booz, Allen & Hamilton
  - Multiple task time estimates
  - Activity-on-arrow network construction

Project Network

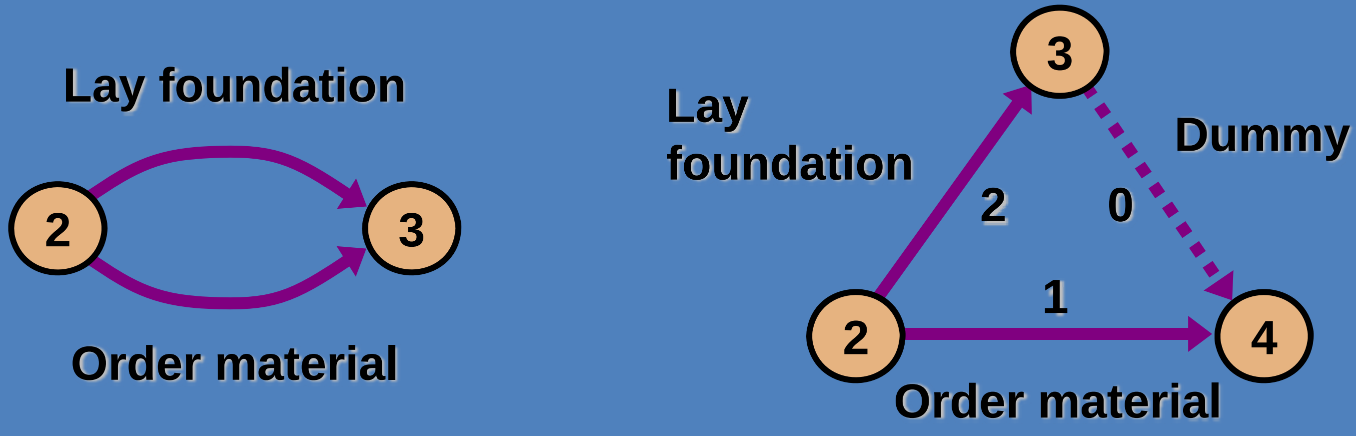
- Activity-on-node (AON)
  - nodes represent activities, and arrows show precedence relationships
- Activity-on-arrow (AOA)
  - arrows represent activities and nodes are events for points in time
- Event
  - completion or beginning of an activity in a project



AOA Project Network for a House



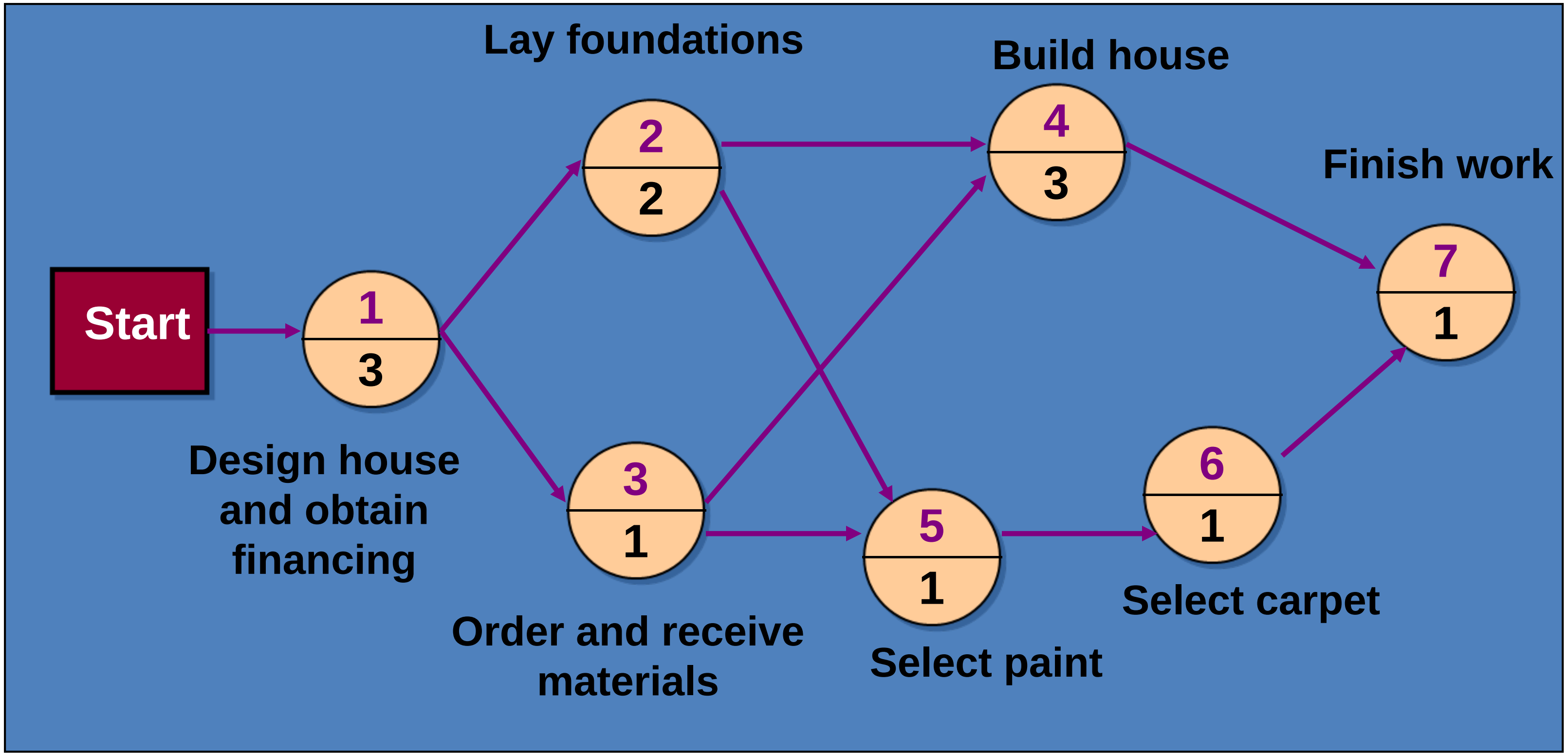
Concurrent Activities



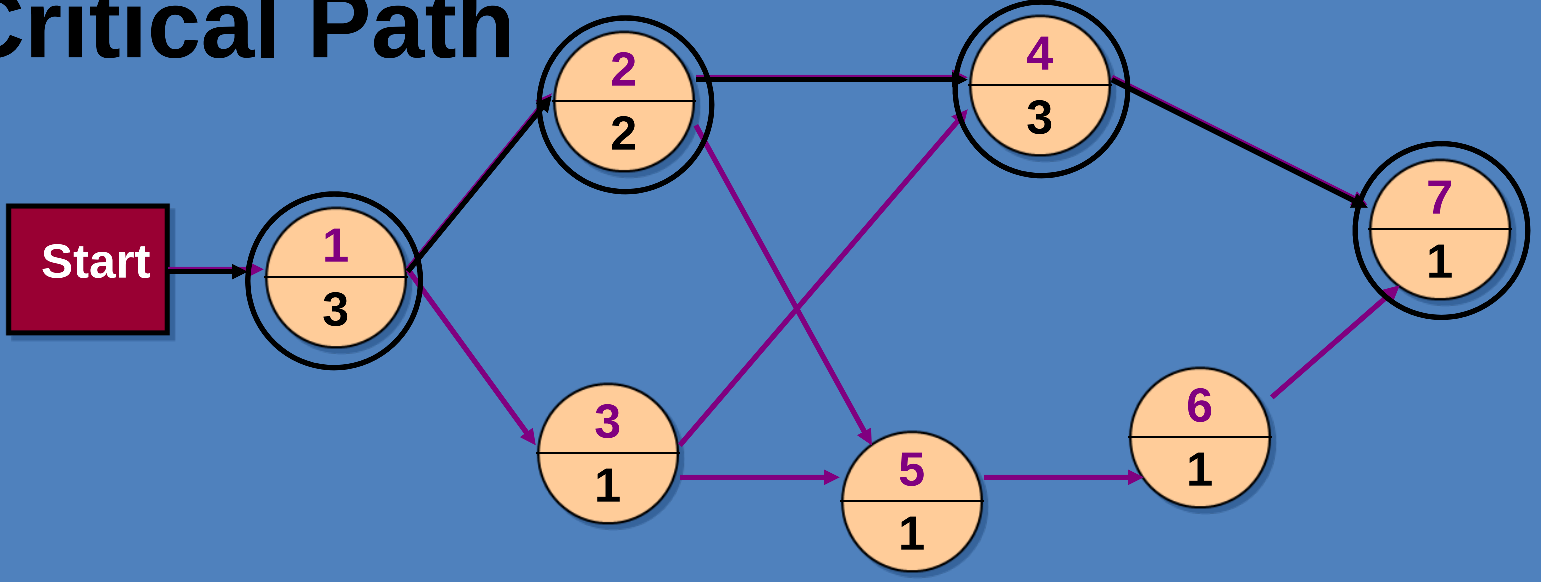
(a) Incorrect precedence relationship

(b) Correct precedence relationship

AON Network for House Project



Critical Path



A: **1-2-4-7**
3 + 2 + 3 + 1 = 9 months

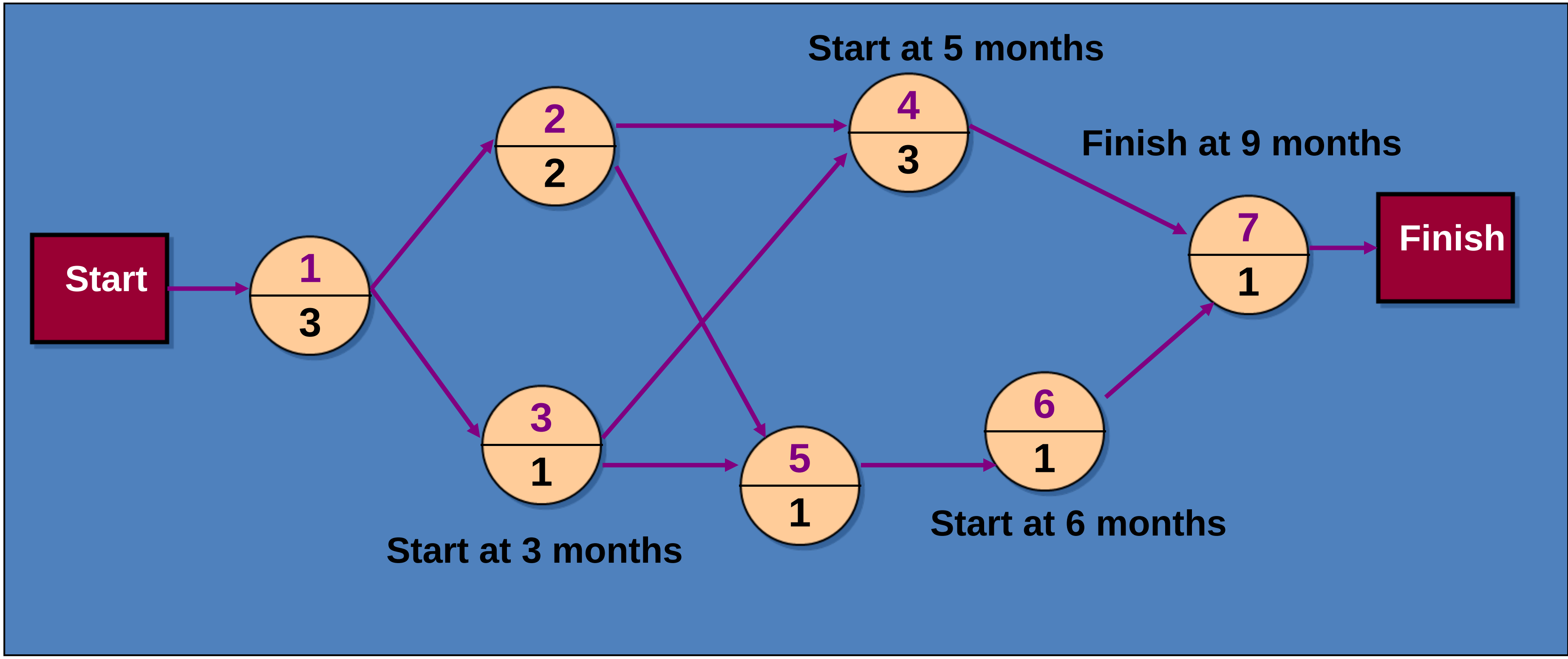
B: 1-2-5-6-7
3 + 2 + 1 + 1 + 1 = 8 months

C: 1-3-4-7
3 + 1 + 3 + 1 = 8 months

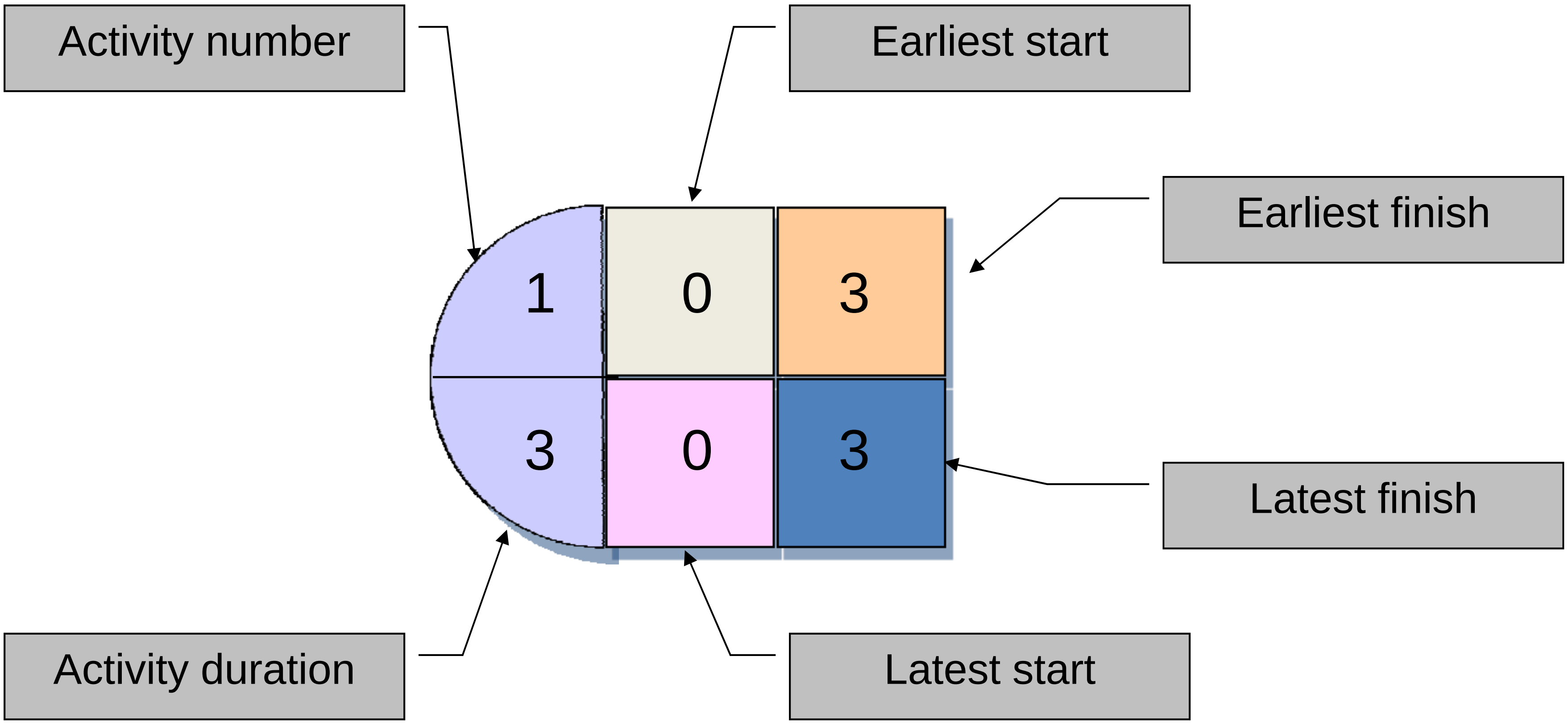
D: 1-3-5-6-7
3 + 1 + 1 + 1 + 1 = 7 months

- Critical path
  - Longest path through a network
  - Minimum project completion time

Activity Start Times



Mode Configuration

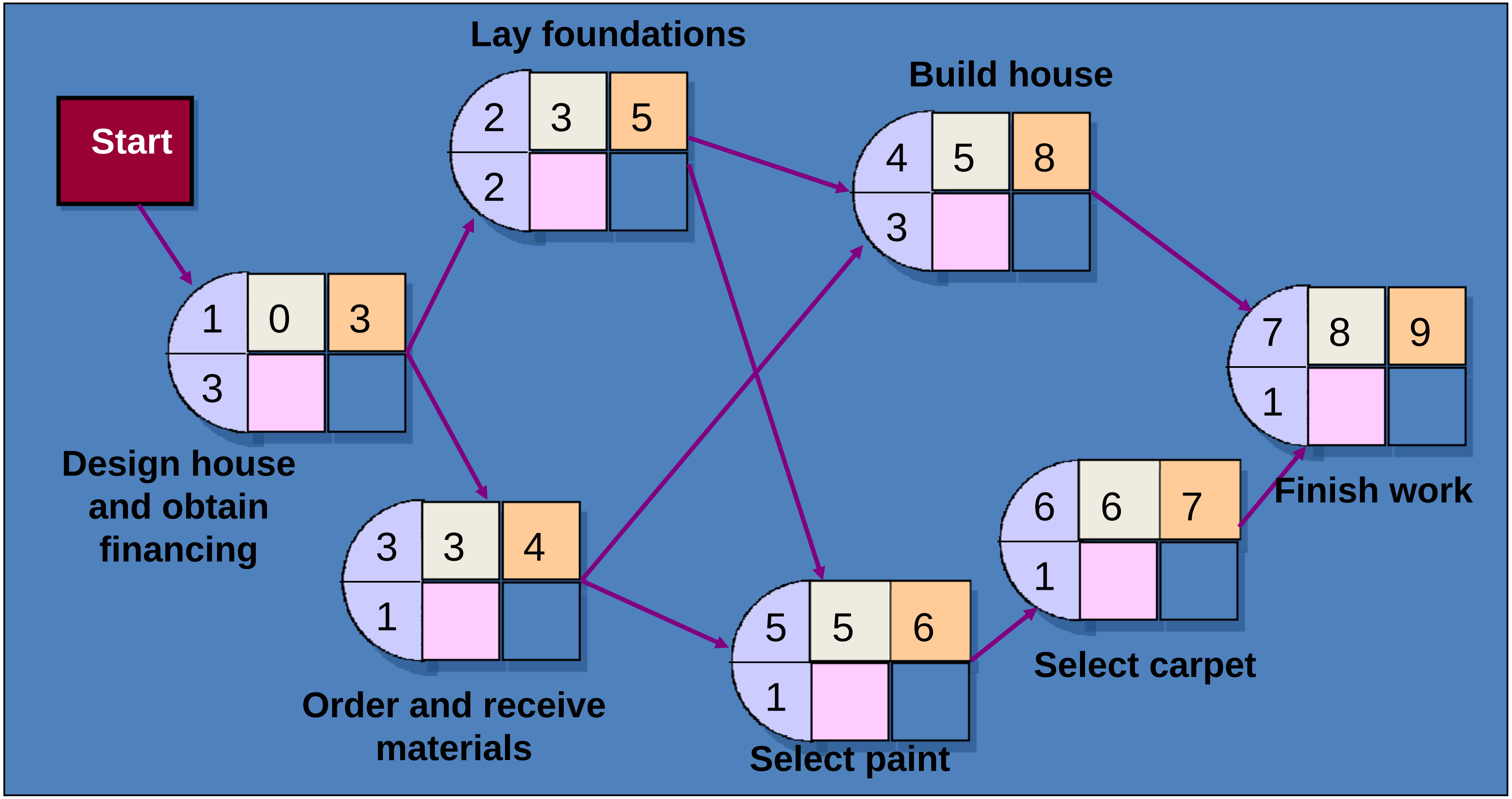


Forward Pass

- Start at the beginning of CPM/PERT network to determine the earliest activity times
- Earliest Start Time (ES)
  - earliest time an activity can start
  - ES = maximum EF of immediate predecessors
- Earliest finish time (EF)
  - earliest time an activity can finish
  - earliest start time plus activity time

$$EF = ES + t$$

Earliest Activity Start and Finish Times



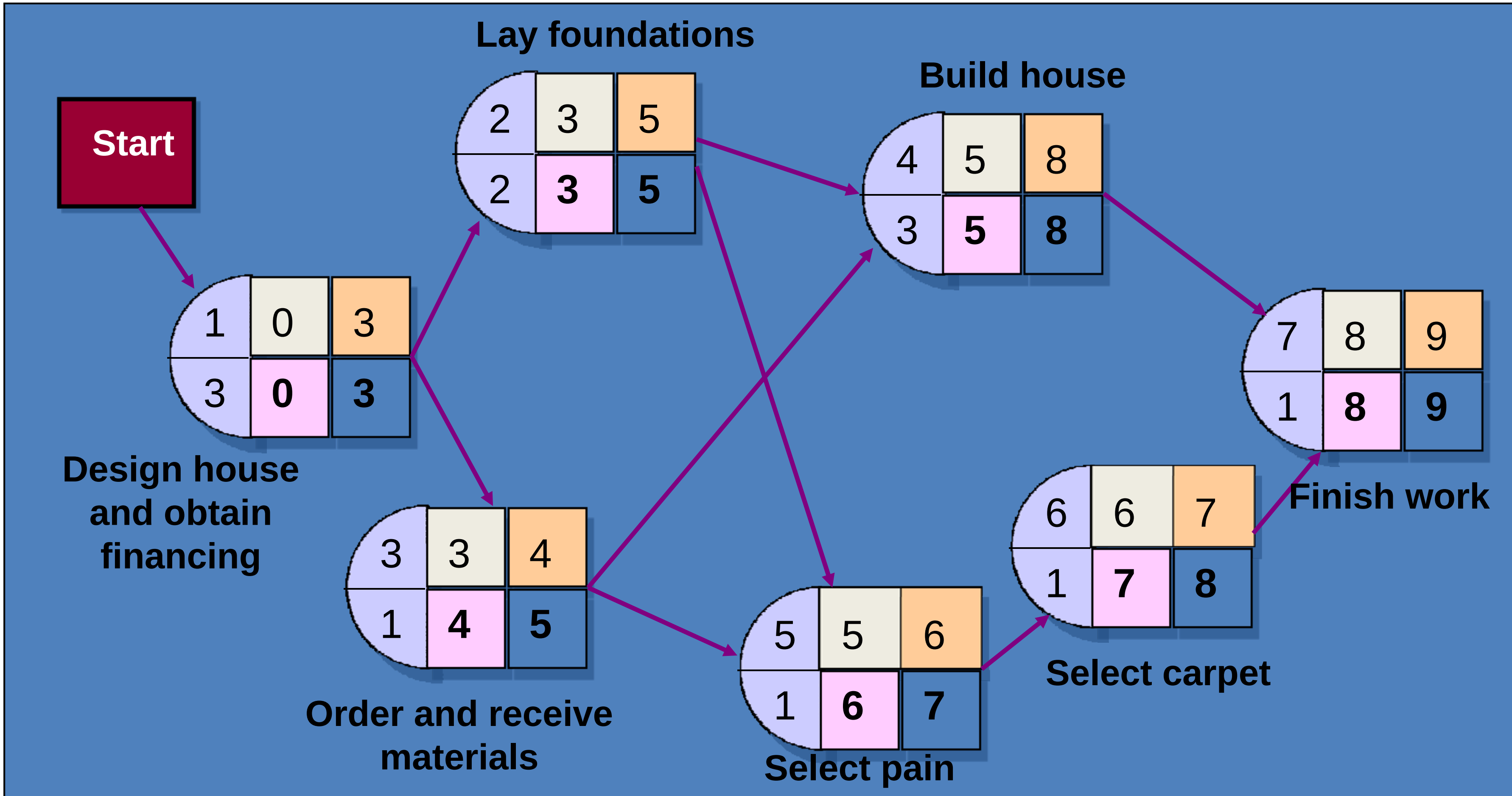
Backward Pass

- Determines latest activity times by starting at the end of CPM/PERT network and working backward
- Latest Start Time (LS)
  - Latest time an activity can start without delaying critical path time

$$LS = LF - t$$

- Latest finish time (LF)
  - latest time an activity can be completed without delaying critical path time
  - LF = minimum LS of immediate predecessors

Latest Activity Start and Finish Times



Activity Slack

Activity	LS	ES	LF	EF	**Slack S**
*1	0	0	3	3	0
*2	3	3	5	5	0
3	4	3	5	4	1
*4	5	5	8	8	0
5	6	5	7	6	1
6	7	6	8	7	1
*7	8	8	9	9	0

* Critical Path

Total Slack vs Free Slack

- Total slack is the time a job could be postponed without delaying the project schedule.
- Total slack = LS – ES = LF – EF
- Free slack is the time a task could be postponed without affecting the early start of any job following it.
- Free slack = the earliest ES of all tasks immediately following this one – EF
- If the total slack is greater than the free slack, then subsequent activities must have some slack in them.

Probabilistic Time Estimates

- Beta distribution
  - a probability distribution traditionally used in CPM/PERT

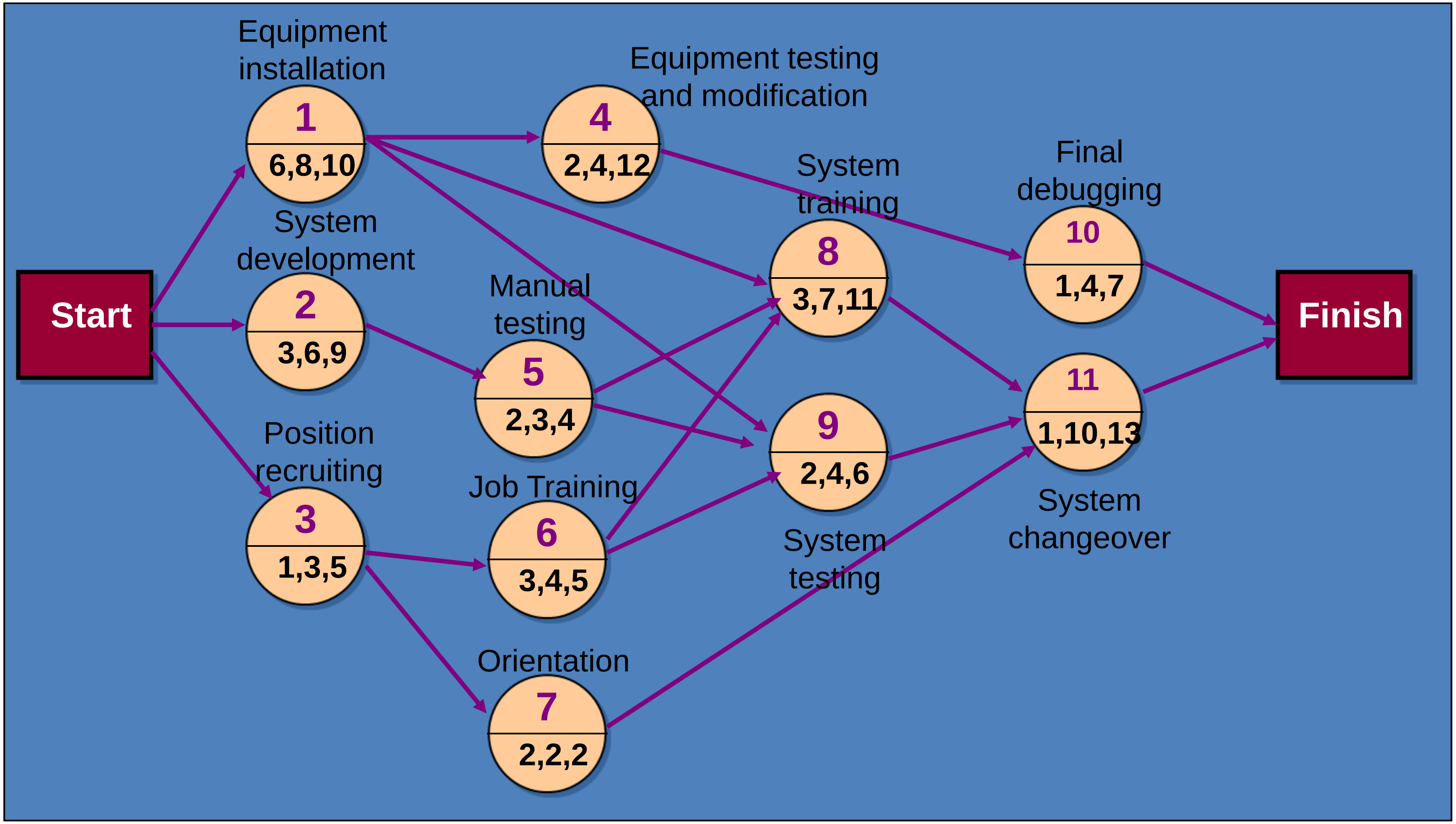
Mean (expected time): $$t = \frac{a + 4m + b}{6}$$

Variance: $$\sigma^2 = \left(\frac{b - a}{6}\right)^2$$

where

a = optimistic estimate
m = most likely time estimate
b = pessimistic time estimate

Project Network with Probabilistic Time Estimates: Example



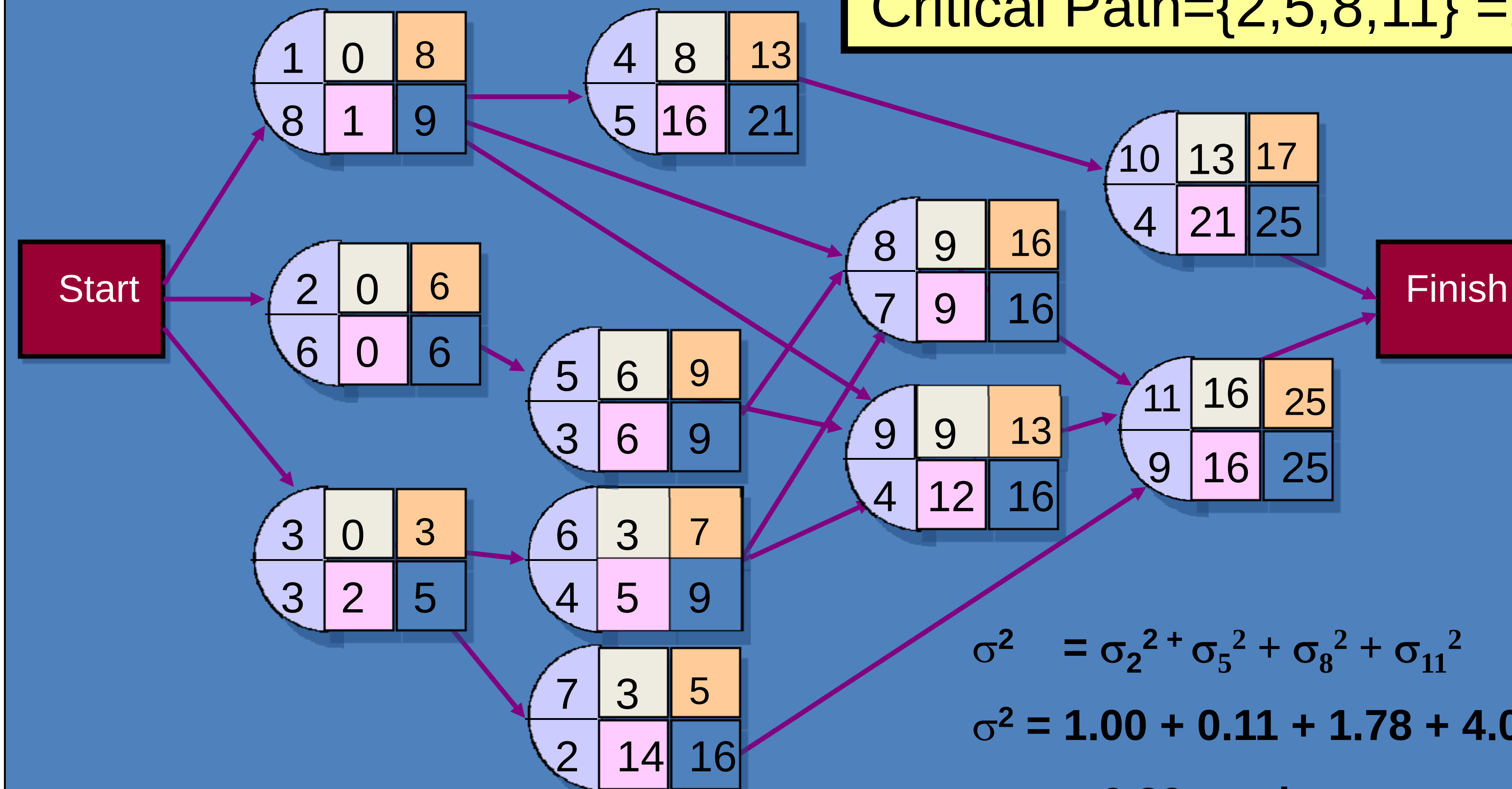
Activity Time Estimates

	TIME ESTIMATES (WKS)			MEAN TIME	VARIANCE
ACTIVITY	*a*	*m*	*b*	*t*	σ^2
1	6	8	10	8	0.44
2	3	6	9	6	1.00
3	1	3	5	3	0.44
4	2	4	12	5	2.78
5	2	3	4	3	0.11
6	3	4	5	4	0.11
7	2	2	2	2	0.00
8	3	7	11	7	1.78
9	2	4	6	4	0.44
10	1	4	7	4	1.00
11	1	10	13	9	4.00

Activity Early, Late Times, and Slack

ACTIVITY	*t*	σ^2	ES	EF	LS	LF	S
1	8	0.44	0	8	1	9	1
2	6	1.00	0	6	0	6	0
3	3	0.44	0	3	2	5	2
4	5	2.78	8	13	16	21	8
5	3	0.11	6	9	6	9	0
6	4	0.11	3	7	5	9	2
7	2	0.00	3	5	14	16	11
8	7	1.78	9	16	9	16	0
9	4	0.44	9	13	12	16	3
10	4	1.00	13	17	21	25	8
11	9	4.00	16	25	16	25	0

Earliest, Latest, and Slack



Critical Path={2,5,8,11} =25

$\sigma^2 = \sigma_2^2 + \sigma_5^2 + \sigma_8^2 + \sigma_{11}^2$

σ^2 = 1.00 + 0.11 + 1.78 + 4.00

= 6.89 weeks

Probabilistic Network Analysis

Determine probability that project is completed within specified time

$$Z = \frac{x - \mu}{\sigma}$$

where

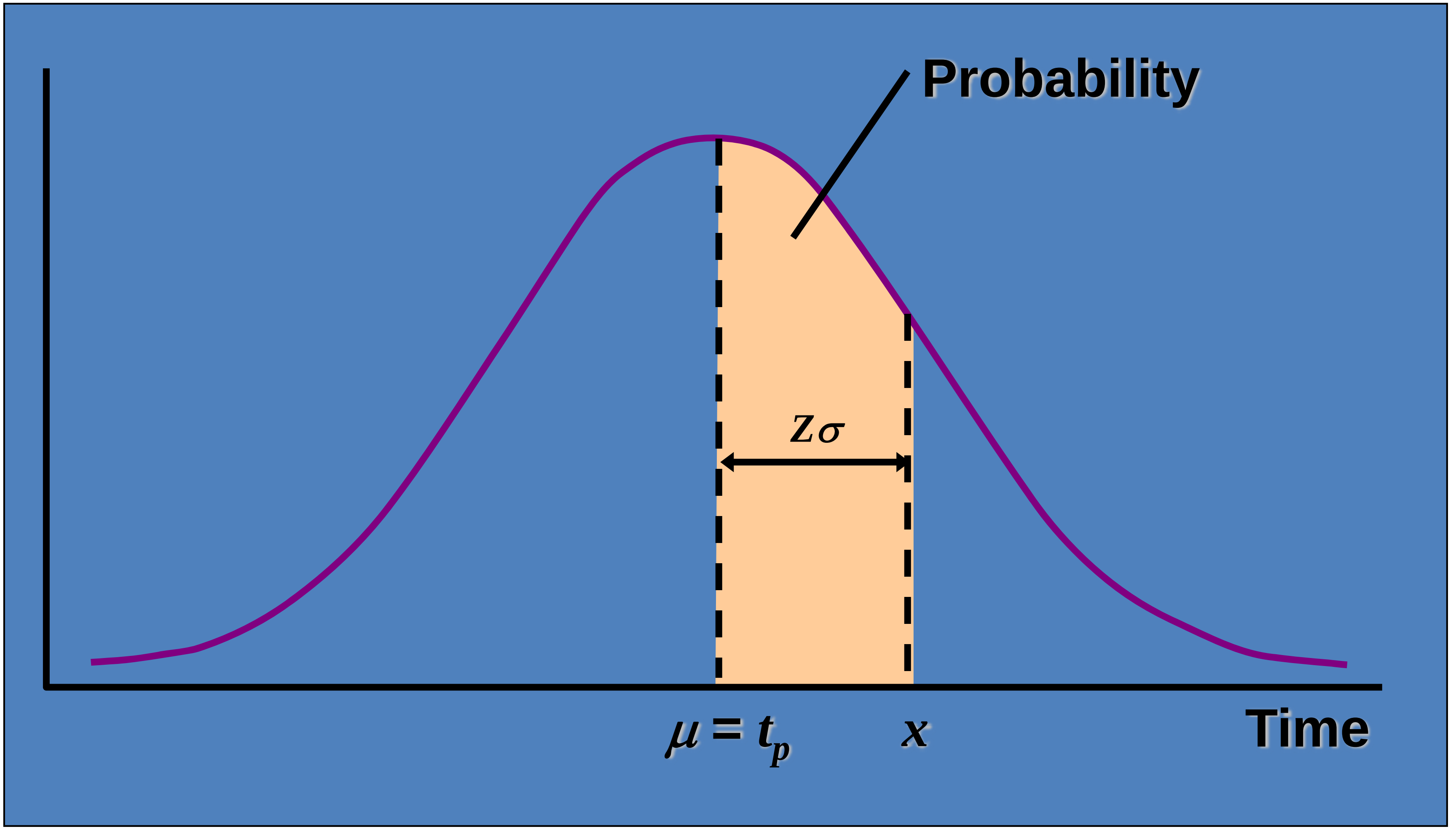
μ = t_p = project mean time

σ = project standard deviation

x = proposed project time

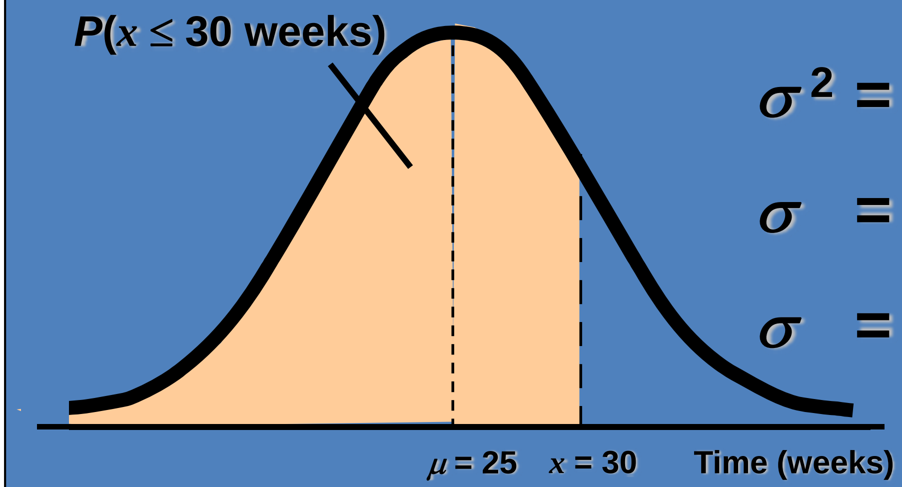
Z = number of standard deviations x is from mean

Normal Distribution Of Project Time



Southern Textile Example

What is the probability that the project is completed within 30 weeks?



$$\sigma^2 = 6.89 \text{ weeks}$$

$$\sigma = \sqrt{6.89}$$

$$\sigma = 2.62 \text{ weeks}$$

$$Z = \frac{x - \mu}{\sigma}$$

$$= \frac{30 - 25}{2.62}$$

$$= 1.91$$

From Table a Z score of 1.91 corresponds to a probability of 0.9719

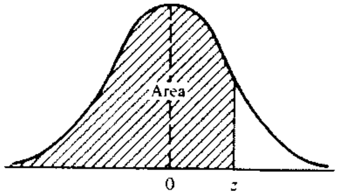


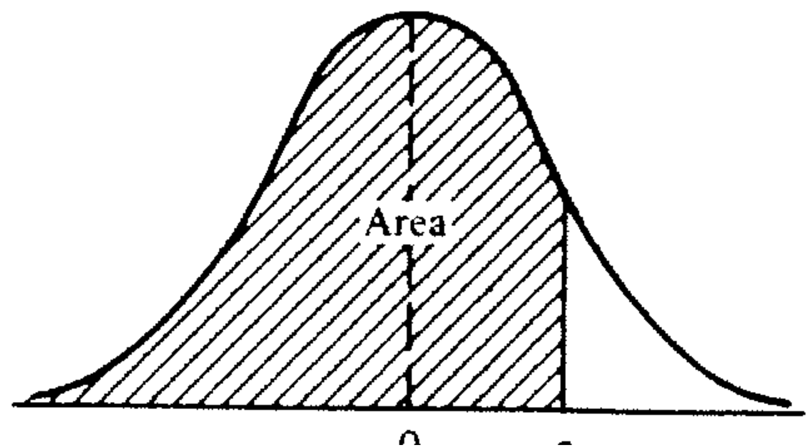
Table IV

Areas Under the Normal Curve

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
−3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
−3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
−3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
−3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
−3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
−2.9	0.0019	0.0018	0.0017	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
−2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
−2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
−2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
−2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
−2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
−2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
−2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
−2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
−2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
−1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
−1.8	0.0359	0.0352	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
−1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
−1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
−1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
−1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0722	0.0708	0.0694	0.0681
−1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
−1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
−1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
−1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
−0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
−0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
−0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
−0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
−0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
−0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
−0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
−0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
−0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
−0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641
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	0.9278	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
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Table IV

Areas Under the Normal Curve



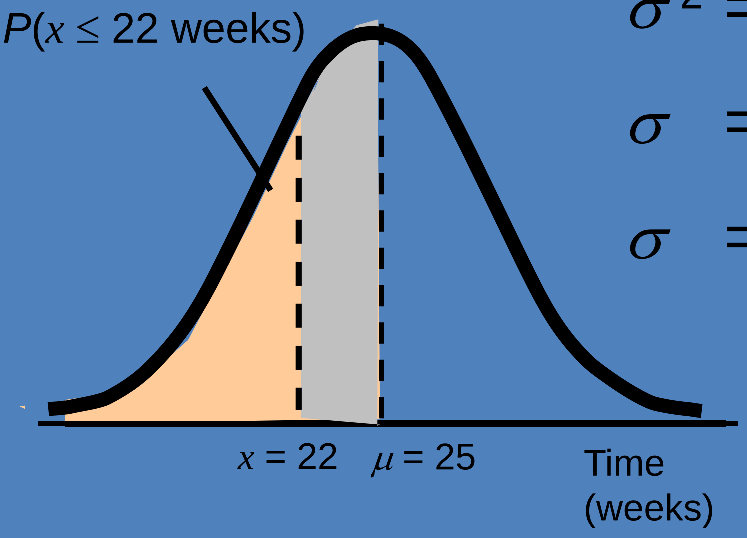
z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
−3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
−3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
−3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
−3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
−3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
−2.9	0.0019	0.0018	0.0017	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
−2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
−2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
−2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
−2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
−2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
−2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
−2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
−2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
−2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
−1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
−1.8	0.0359	0.0352	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
−1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
−1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
−1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559

−1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0722	0.0708	0.0694	0.0681
−1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
−1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
−1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
−1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
−0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
−0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
−0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
−0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
−0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
−0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
−0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
−0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
−0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
−0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641
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	0.9278	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
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Southern Textile Example

What is the probability that the project is completed within 22 weeks?



$\sigma^2 = 6.89$ weeks

$\sigma = \sqrt{6.89}$

$\sigma = 2.62$ weeks

$$Z = \frac{x - \mu}{\sigma} = \frac{22 - 25}{2.62} = -1.14$$

From Table a Z score of -1.14 corresponds to a probability of 0.1271

Project Crashing

- Crashing
  - reducing project time by expending additional resources
- Crash time
  - an amount of time an activity is reduced
- Crash cost
  - cost of reducing activity time
- Goal
  - reduce project duration at minimum cost

Excavation

Problem 1

Fill Volume

Using grid shown in figure 3, please determine the fill quantity for Grid 13 (F2-G2-F3-G3 grid). Use figures 1 and 2 for site elevation information.

$$\text{cf of fill} = \frac{\text{Sum of fill at intersections}}{\text{Number of intersections}} \times \text{area}$$

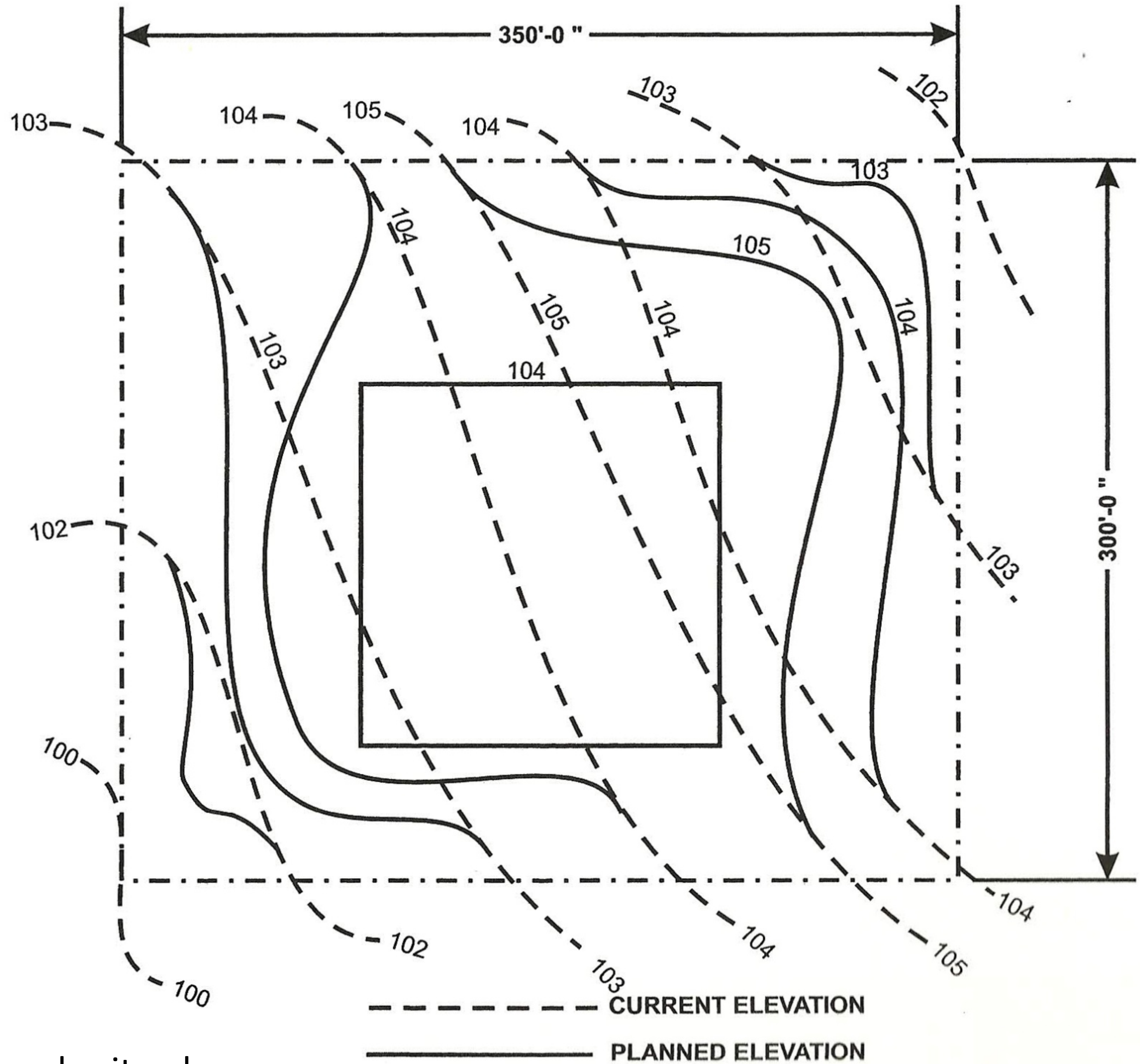


Figure 1 Sample site plan

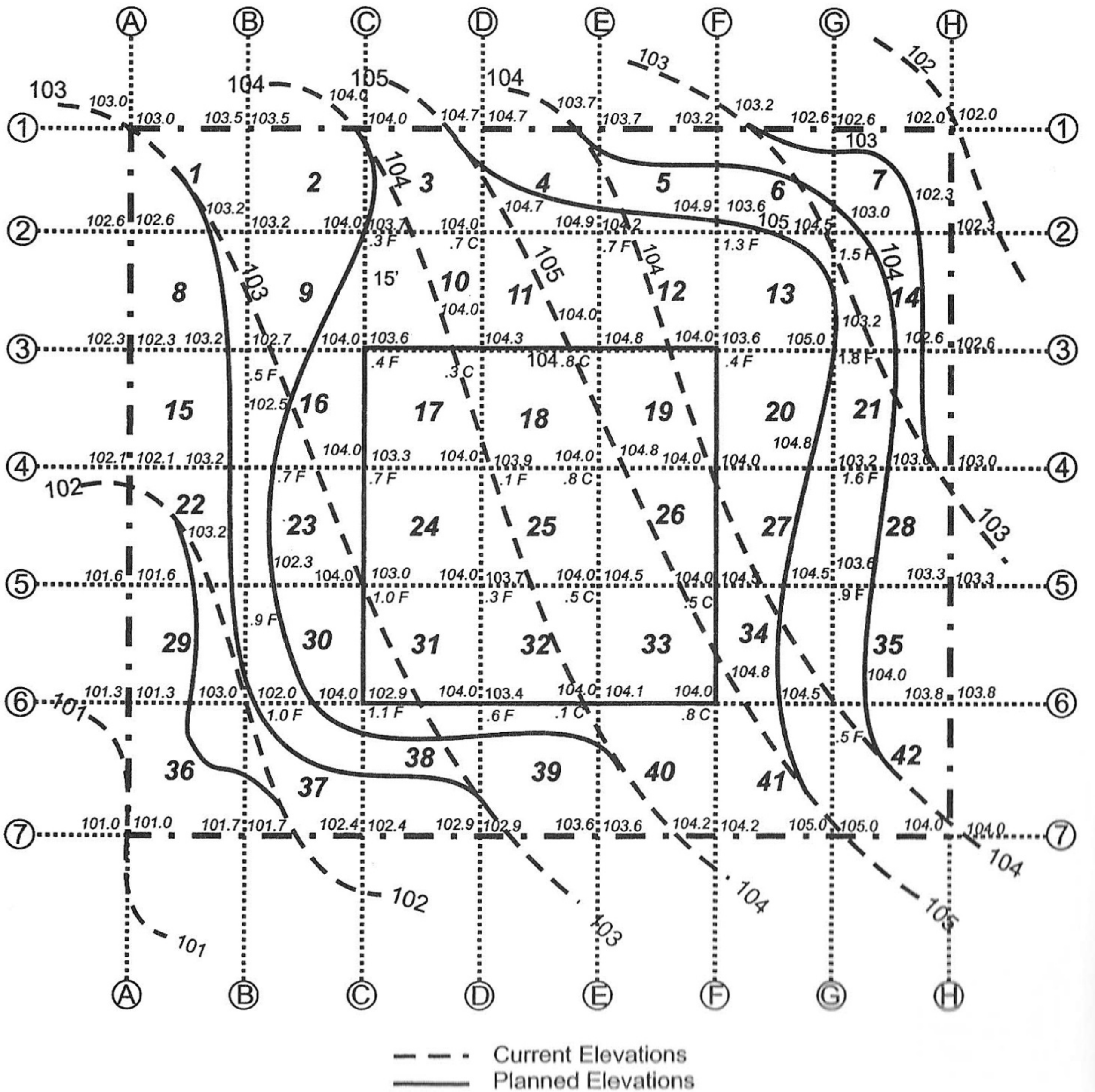
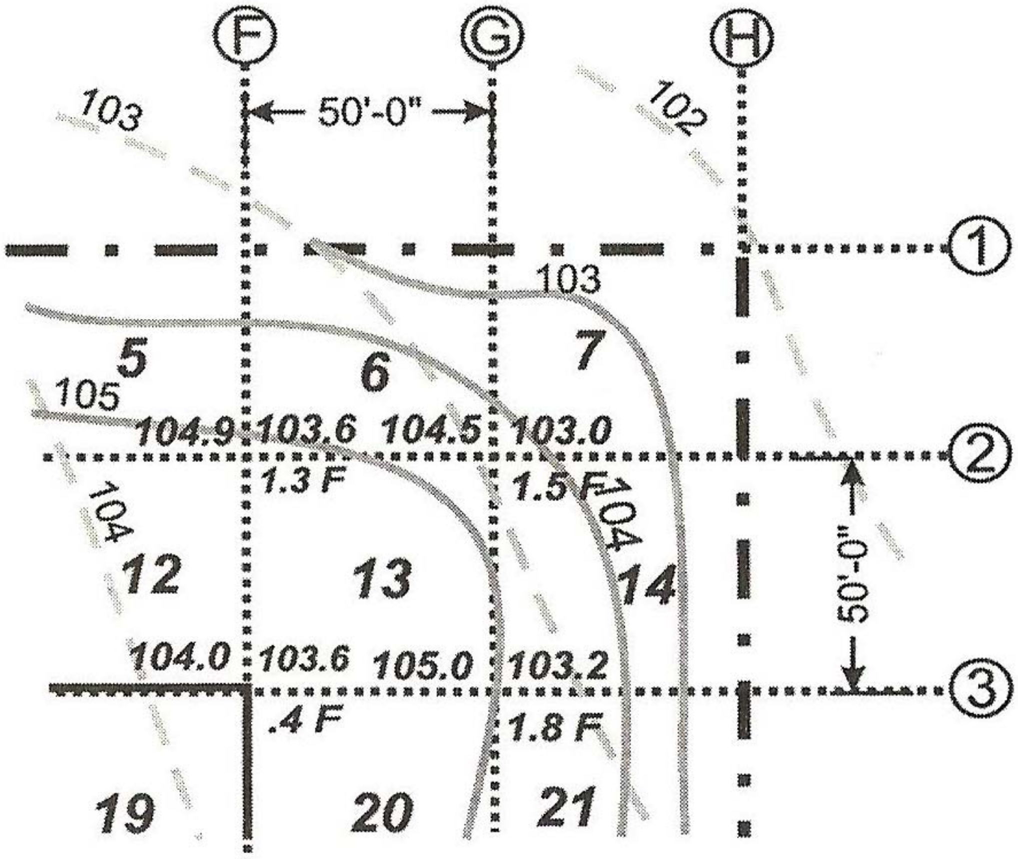


Figure 2 Site Plan Divided in 50 ‘ Square Grid with Elevations



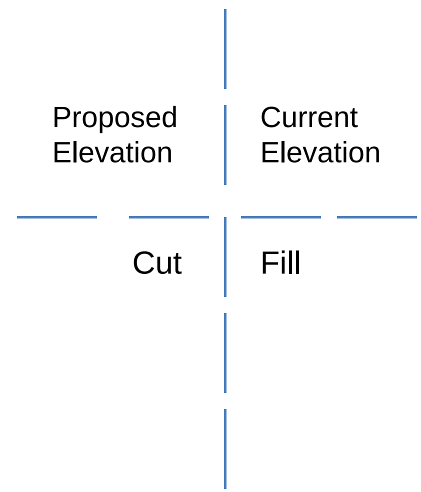


Figure 3 -- Excerpt from Figure 2

Problem 1 (continued) Fill Volume

Using grid shown on Figure 3 in slide 4, please determine the fill quantity for the F2-G2-F3-G3 grid. Use figures 1 and 2 for site elevation information.

$$\text{cf of fill} = \frac{\text{Sum of fill at intersections}}{\text{Number of intersections}} \times \text{area}$$

$$\frac{1.3' + 1.5' + .4' + 1.8'}{4} \times 2{,}500 \text{ sf} = 3{,}125 \text{ cf of fill}$$

Point	Planned Elevation	Existing Elevation	Fill (ft)
F2	104.9’	103.6’	1.3
G2	104.5’	103.0’	1.5
F3	104.0’	103.6’	.4
G3	105.0’	103.2’	1.8

Figure 4 Data for grid 13

Problem 1 --- Cut Volume

Using the information in grid 40 from figure 2, please find the volume of fill in that grid.

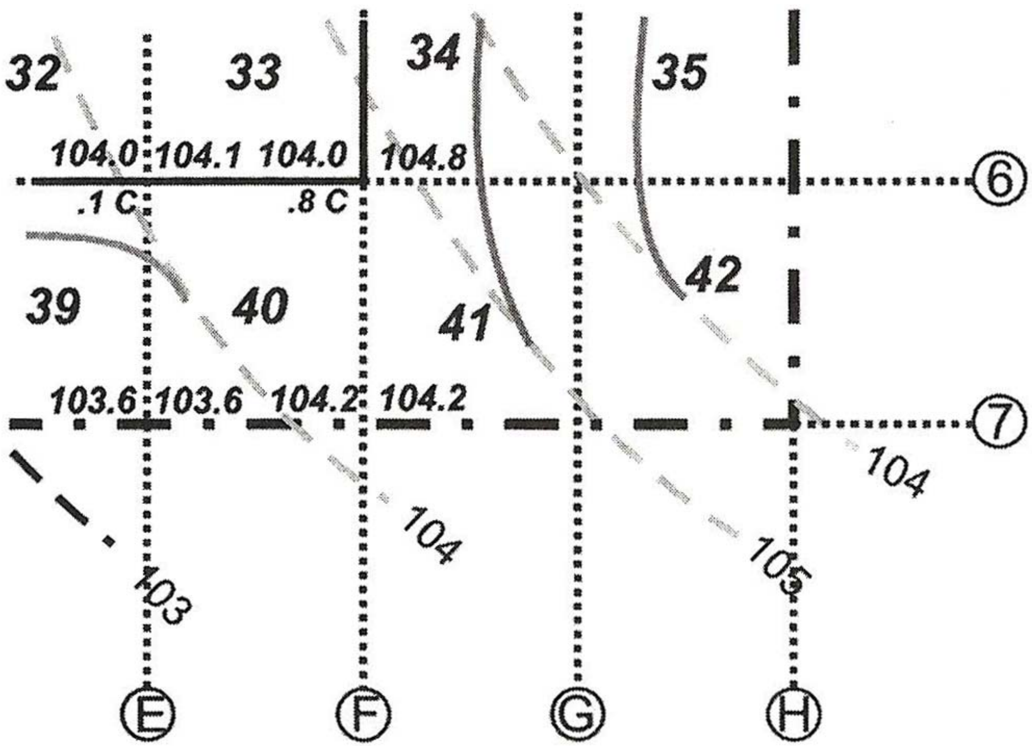


Figure 5 excerpt of grid 40

Problem 1 (continued) --- Cut Volume

The volume of a cut is determined in exactly the same way as fill. Using the information in table below which is known from using grid 40 from figure 2, please find the volume of fill in that grid.

$$\frac{.1' + .8' + 0' + 0'}{4} \times 2{,}500 \text{ sf} = 563 \text{ cf of cut}$$

Point	Planned Elevation	Existing Elevation	Cut (ft)
E6	104.0’	104.1’	0.1
F6	104.0’	104.8’	0.8
E7	103.6’	103.6’	0.0
F7	104.2’	104.2’	0.0

Figure 6 data for grid 40

Problem 2 - cut and fill

Grid 10 from figure 2 is an example of a square that contains both cut and fill. Please use the elevation information given to find the volume of cut and fill in grid 10.

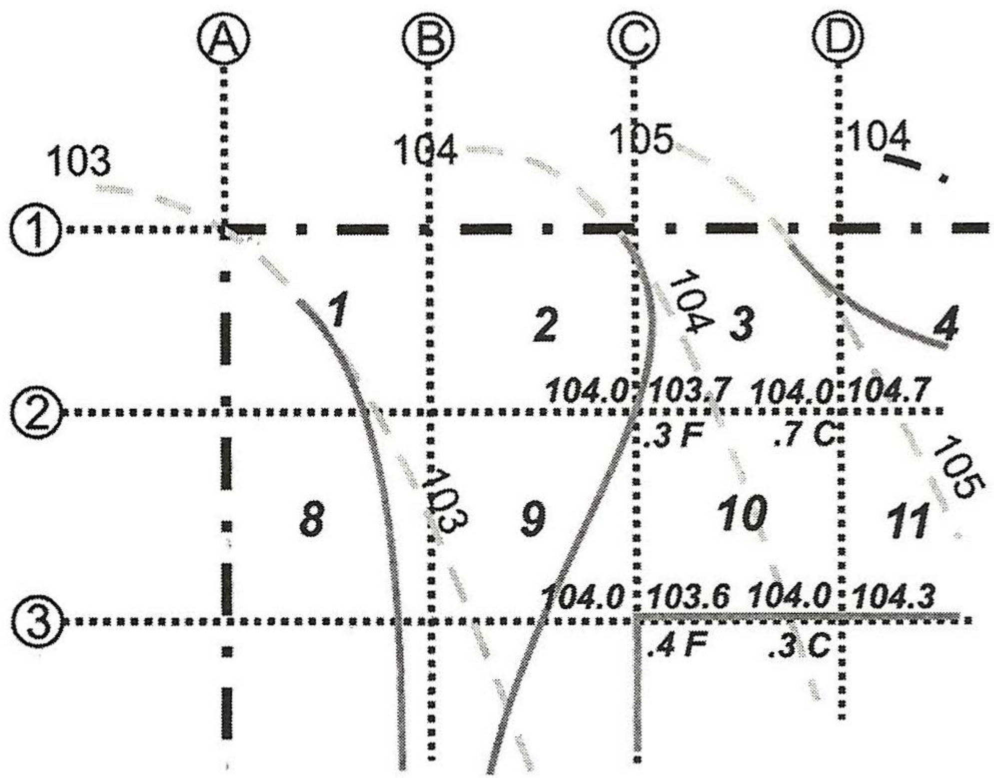


Figure 7 elevation information for grid 10

Problem 2 (continued) - cut and fill

Grid 10 from figure 7 is an example of a square that contains both cut and fill. Along line 2, somewhere between lines C and D, there is a point where there is no change in elevation. This point is found first by determining the total change in elevation and dividing that amount by the distance between the points; second, determine the change in elevation per foot of run.

Total change in elevation (C-D) = .3’ + .7’ = 1.0’ change in elevation

Change in elevation per foot of run (C-D) = 1.0’ / 50’ = .02’ per foot of run

Because the elevation change is .02 foot per foot of run, you can determine how many feet must be moved along that line until there has been a .3-foot change in elevation.

.3’ / .02’ per foot of run = 15’

Problem 2 (continued) - cut and fill

This means that as one moves from point C2 toward point D2 at 15 feet past point C2 there is the theoretical point of no change in elevation, or the transition point. Because the same thing occurs along line 3 between points C3 and D3, the same calculations are required.

Total change in elevation (C-D) = .4’ + .3’ = .7’ change in elevation

Change in elevation per foot of run (C-D) = .7’ / 50’ = .014 per foot of run

From this calculation the distance from point C3 to the point of no change in elevation can be found.

.4’ / .014’ per foot of run = 29’

Problem 2 (continued) - cut and fill

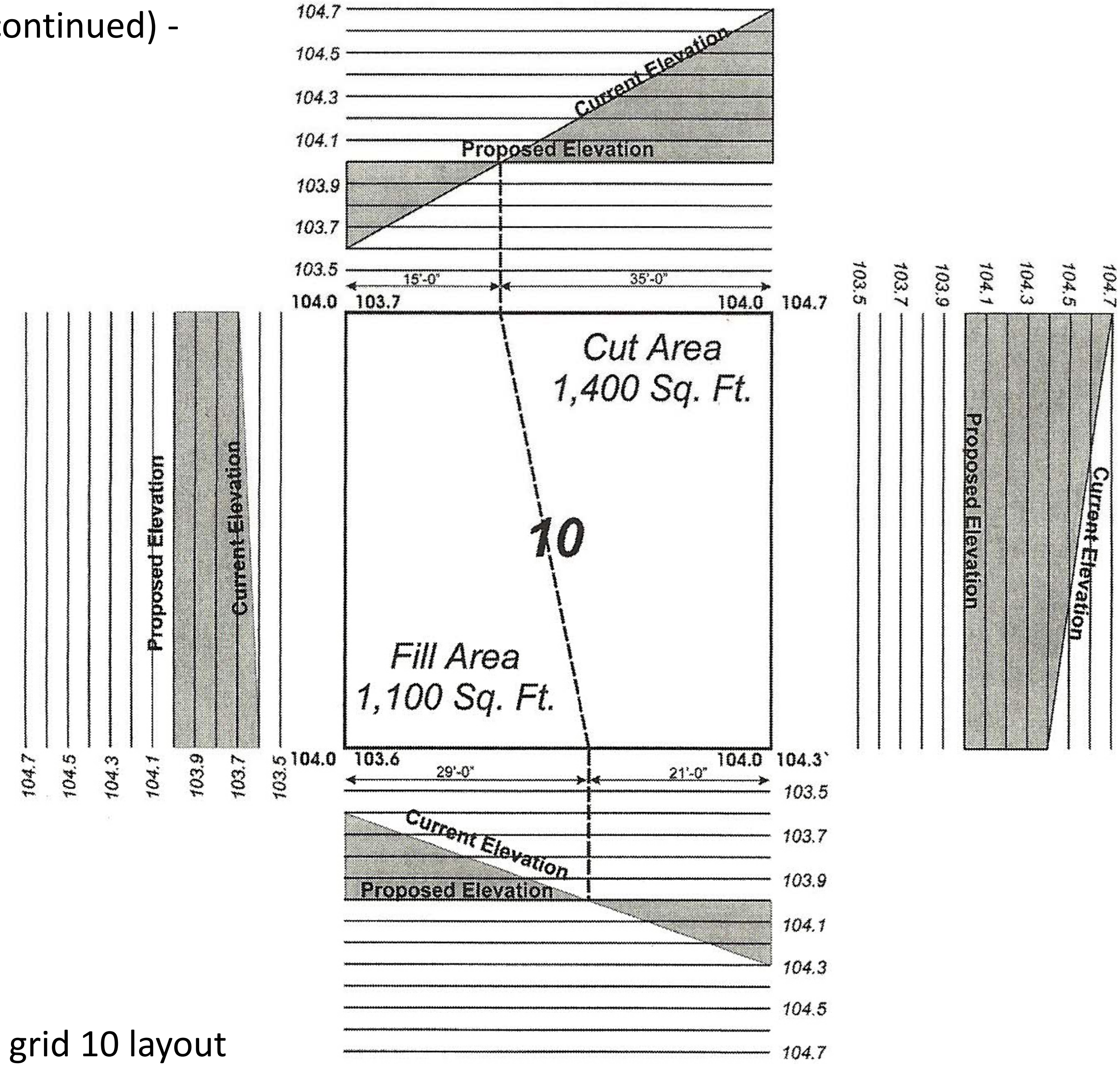


Figure 8 --- grid 10 layout

Problem 2 (continued) - cut and fill

Given this information, grid 10 can be divided into two distinct grids; one for cut and one for fill. Figure 8 details how the grid would be divided.

The next step is to determine the area of the cut and fill. The most simple is to divide the areas into rectangles and/or triangles.

Fill area = 15’ x 50’ = 750 sf

Fill area = .5 x 14’ x 50’ = 350 sf

Total fill area = 750 sf + 350 sf = 1,100 sf

$$\frac{.3 + .4' + 0' + 0'}{4} \times 1{,}100 \text{ sf} = 193 \text{ cf of fill}$$

Cut area = 2,500 sf – 1,100 sf = 1,400 sf

$$\frac{.3 + .7' + 0' + 0'}{4} \times 1{,}400 \text{ sf} = 350 \text{ cf of cut}$$

Problem 3 – Top Soil Removal

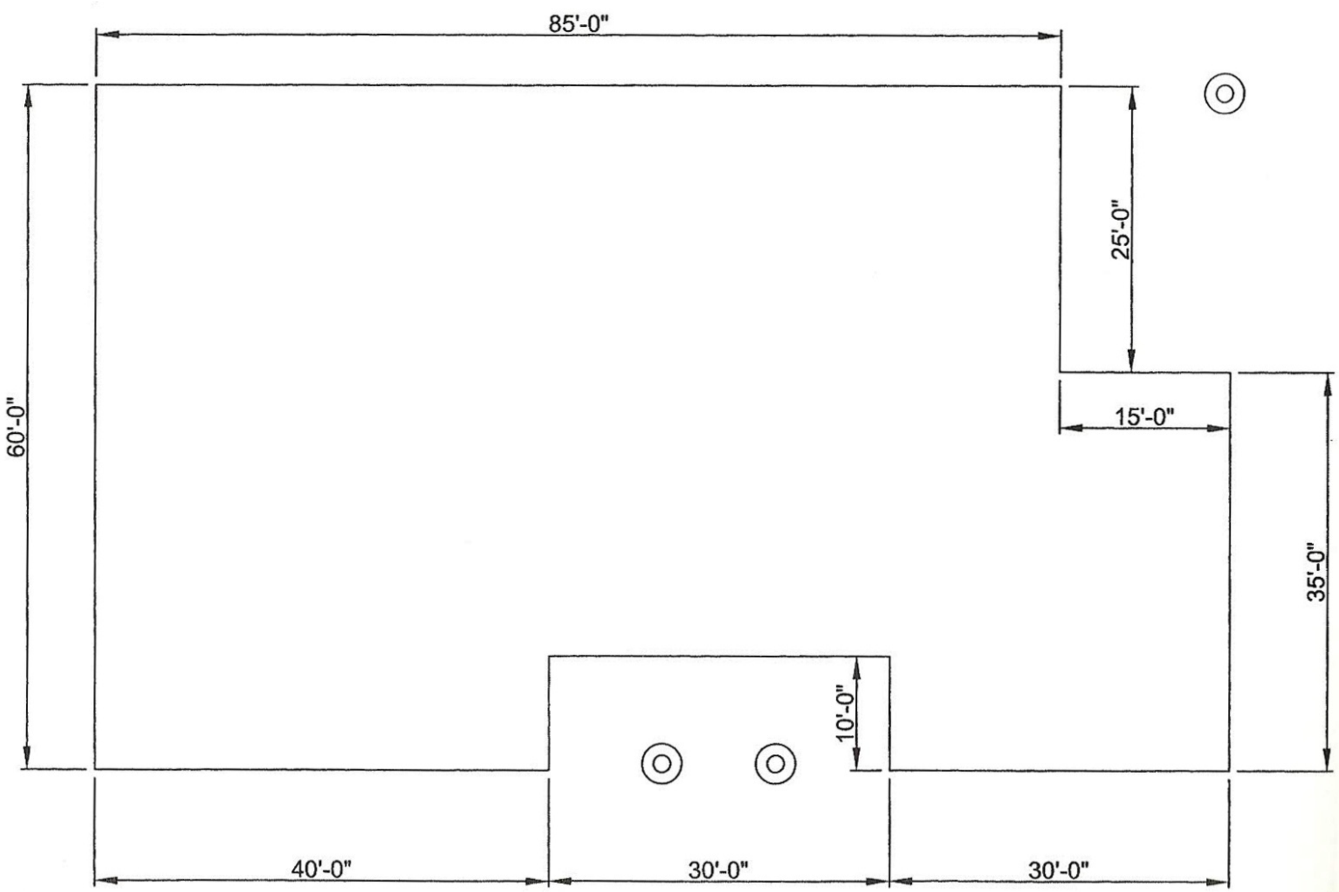


Figure 9

Problem 3 (continued)

Find the perimeter of the building shown in figure 9. Starting in the upper left corner of the building and proceeding clockwise:

85’ + 25’ + 15’ + 35’ + 30’ + 10’ + 30’ + 10’ + 40’ + 60’ = 340’

Find the building area of the building shown in figure 9

Basic area 100’ x 60’	6,000	sf
Bottom recess 10’ x 30’	- 300	sf
Top recess 15’ x 25’	- 375	sf
Net building area	5,325	sf

Quantity of topsoil to be removed (cf) = $110' \times 70' \times .75' = 5{,}775$ cf

Or 5,775 cf / 27 cf per cy

cy = 214 cy

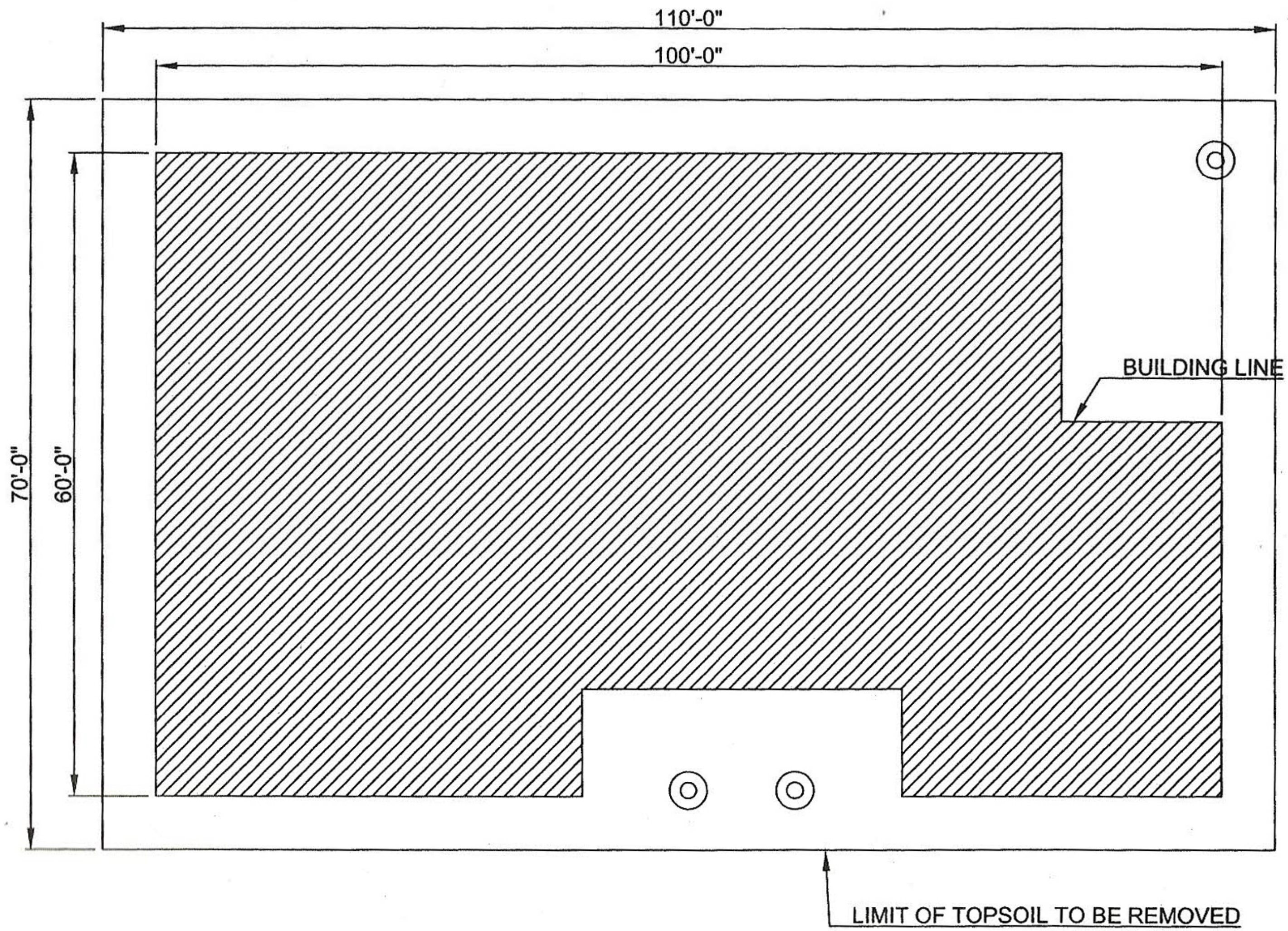


Figure 10 topsoil quantity

Problem 3 (continued)

Please find the volume of topsoil to be removed for site development for the site shown in Figure 10.

In figure 10, the "footprint" of the building from figure 9 has been enlarged by 5 feet on each side to compensate for accuracy and slope. Assume that the topsoil to be removed is 9 inches thick.

Quantity of topsoil to be removed (cf) = 110' x 70' x .75' = 5,775 cf

Or 5,775 cf / 27 cf per cy

Cy = 214 cy

Problem 3 (continued)

Equipment selection for the removal of topsoil will probably be limited to either a bulldozer or front-end loader. Assume that a 1 cy bucket front-end loader is selected (see figures 10 and 12) and its production rate is estimated to be an average of 24 cy per hour. Mobilization time is estimated at 2.5 hours, the operating cost per hour for the equipment is estimated at $22.80, and the cost for an operator is $29.95 per hour. Estimate the number of hours and the cost.

Problem 3 (continued)

Soil	Dozer				Tractor shovel		Front end loader		Backhoe	
	50 ' haul		100' haul		No haul		50' haul	100' haul	No haul	
	50 hp	120 hp	50 hp	120 hp	1 c.y..	2.25 c.y.	1 c.y.	2.25 c.y..	.5 c.y..	1 c.y..
Medium	40	100	30	75	40	70	24	30	25	55
Soft, sand	45	110	35	85	45	90	30	40	25	60
Heavy soil or stiff clay	15-20	40	10-15	30-35	15-20	35	10	12	10	15

Figure 11 Equipment Capacity (cy per Hour)

Load and haul		
Truck size	Haul	c.y.
6 c.y.	1 mile	12-16
6 c.y.	2 miles	8-12
12 c.y.	1 mile	18-22
12 c.y.	2 miles	12-14

Figure 12 Truck Haul (cy per Hour)

Problem 3 (continued)

First, the total work hours required to complete the topsoil removal must be calculated. Divide the total cubic yards to be excavated by the rate of work done per hour, and add the mobilization time; the answer is the total hours for this phase of work.

$$\frac{214 \text{ cy}}{24 \text{ cy per hour}} + 2.5 \text{ hours} = 11.4 \text{ hours}$$

The total number of hours is then multiplied by the cost of operating the equipment per hour, plus the cost of the crew for the period of time.

Equipment cost = $22.80 per hour x 11.4 hours = $260
Labor cost = $29.95 per work hour x 11.4 hours = $341

Problem 4 - Basement Excavation

Material	Angle		
	Wet	Moist	Dry
Gravel	15-25	20-30	24-40
Clay	15-25	25-40	40-60
Sand	20-35	35-50	25-40

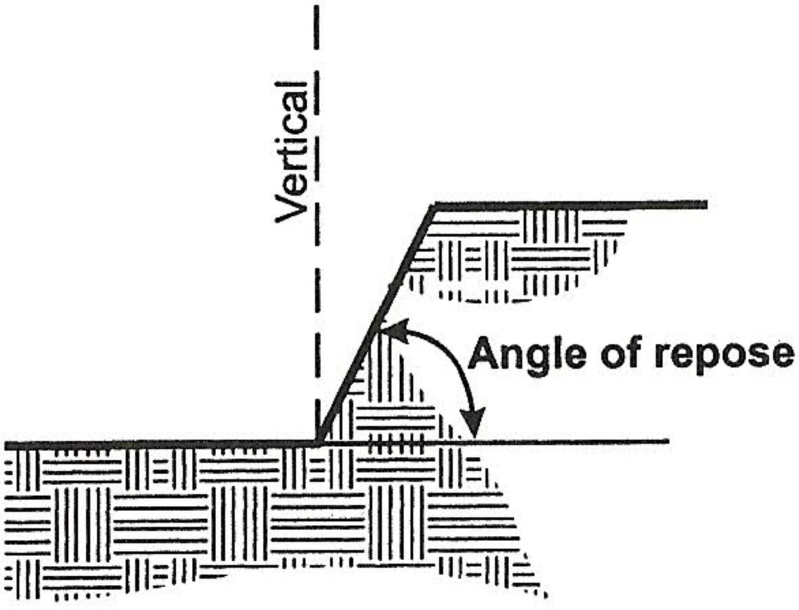


Figure 13 Angle of Repose

Problem 4 (continued) - Basement Excavation

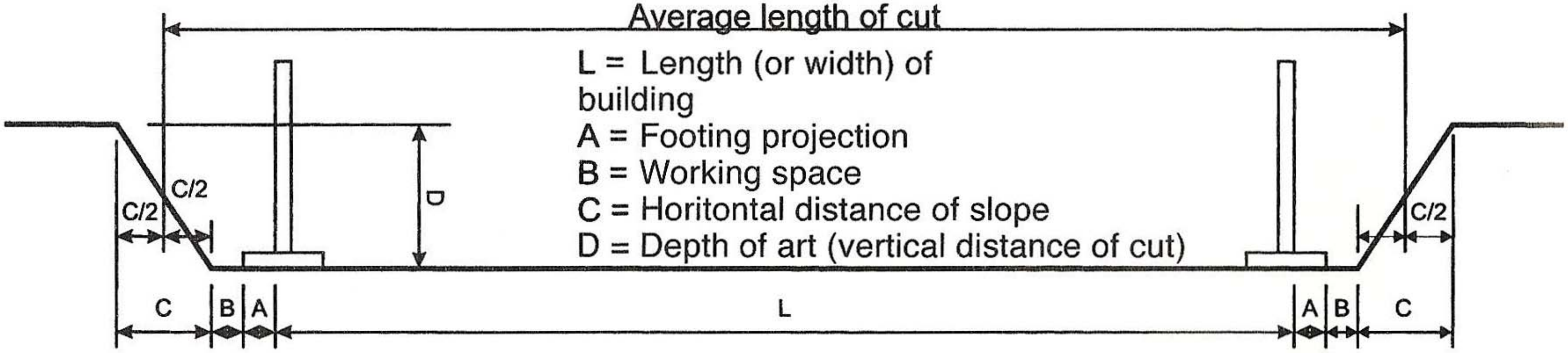


Figure 14 Typical Excavation

Problem 4 (continued) - Basement Excavation

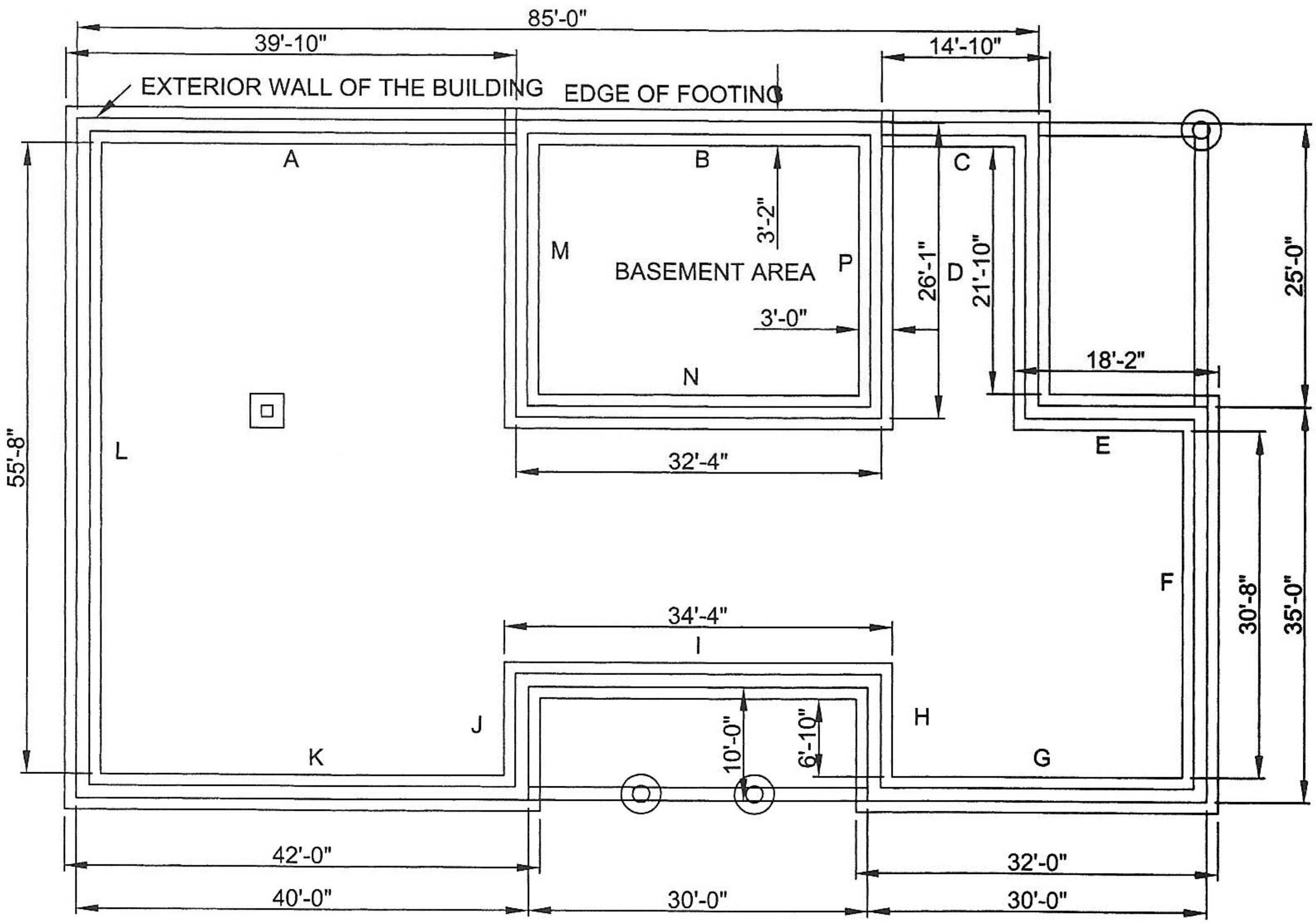


Figure 15 Building Plan

Problem 4 (continued) - Basement Excavation

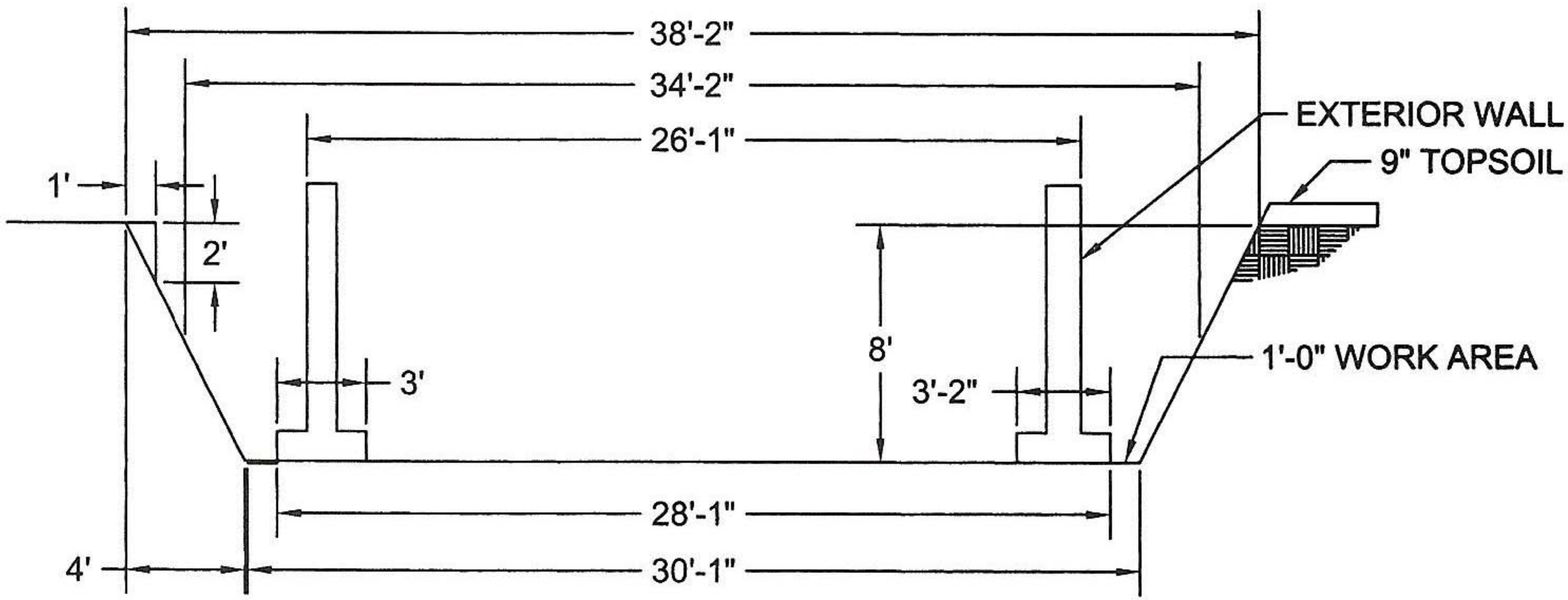


Figure 16 Basement Cross-Section

Problem 4 (continued) - Basement Excavation

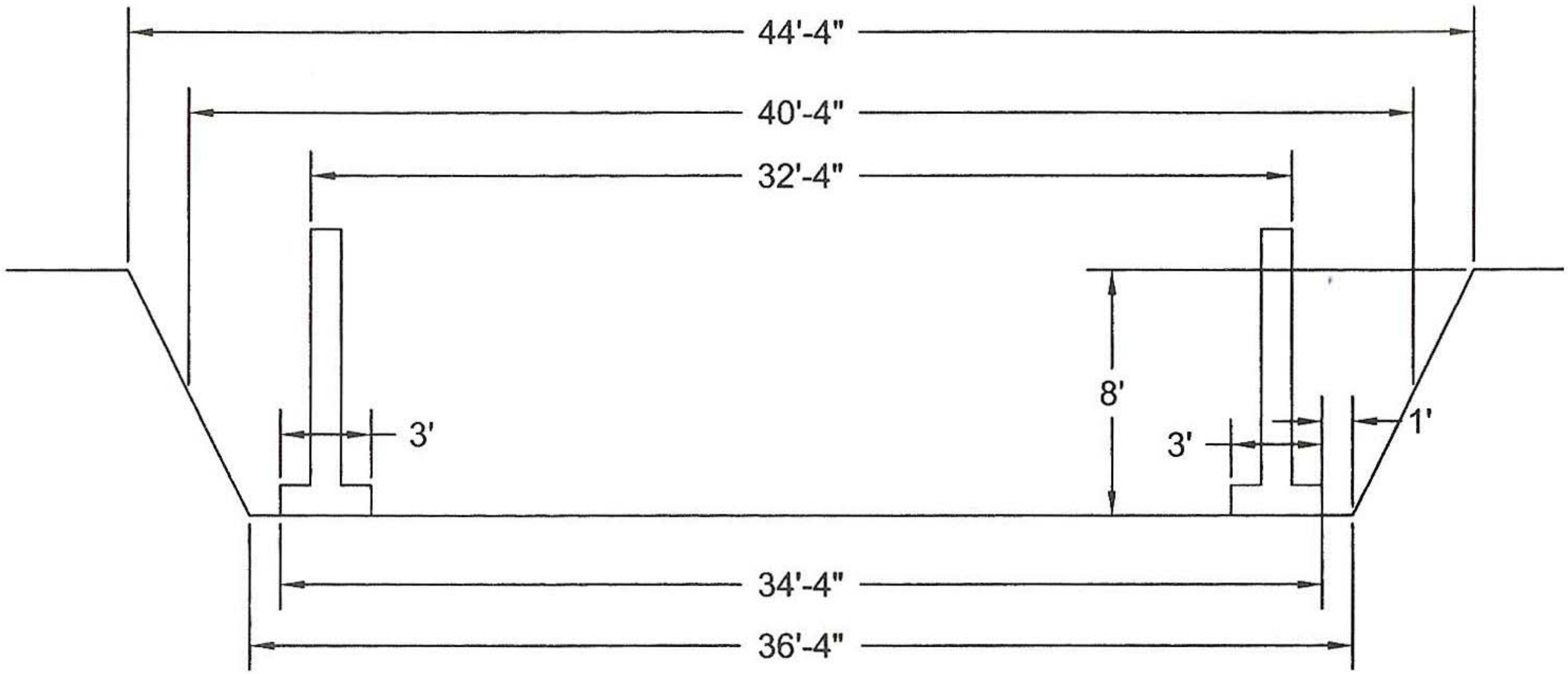


Figure 17 Basement Cross-Section

Problem 4 (continued) - Basement Excavation

Determine the amount of general excavation required for the basement portion of the building shown in figure 15. To get information about this building, look at the building/wall sections.

1. From the building plan, the exterior dimensions of the basement are 26’1” by 32’4”.
2. From the wall section, the footing projects out 1 foot from the foundation wall.
3. The workspace between the edge of the footing and the beginning of the excavation will be 1 foot in this example.
4. The elevation of the existing land, by checking the existing contour lines on the plot (site) plan, is found and noted. In this example the expected depth of the cut is 8 feet after a deduction for the topsoil that would have already been removed.
5. Check the soil borings. For this example a slope of 2:1 will be used (which means for every 2 feet of vertical depth an additional 1 foot of horizontal width is needed). Since the alternative is shoring or sheet piling on this project, the sloped excavation will be used.
6. The bottom elevation of the general excavation cut will be at the bottom of the gravel. Since this elevation is rarely given, it may have to be calculated. Generally, the drawings will give the elevation of the basement slab or bottom of the footing; the depth of cut is calculated from these:

Problem 4 (continued) - Basement Excavation

Average Width of Cut:
2’0’ + 1’0” + 28’1” + 1’0” + 2’0” = 34’1”

Average Length of Cut:
2’0” + 1’0” + 34’4” + 1’0” + 2’0” = 40’4”

General Excavation:
General excavation (cy) = 34’1” x 40’4” x 8’
General excavation (cy) = 34.083’ x 40.33’ x 8’ = 10,997 cf
10,997 cf / 27 cf per cy = 407 cy

Required equipment: Backhoe with 1-cy bucket
Mobilization: 2 hours
Rate of work for backhoe: 55 cy per hour
Equipment cost: $28.75 per hour
Operator cost: $39.75 per hour

Problem 4 (continued) - Basement Excavation

Equipment hours = 407 cy / 55 = 7.4 hours
Total hours = 7.4 equipment hours + 2 hours for mobilization
= 9.4 hours
Equipment $ = 9.4 hours x $28.75 per hour = $270
Labor $ = 9.4 hours x $39.75 per hour = $373.65

If this were to be hauled off the site, assuming a 30% swell factor, it would take 76 loads using a 7 cy truck.

Required haul (cy) = 407 cy x 1.3 = 529 cy
Required loads = 529 cy / 7 cy per load = 76 loads

Problem 5 - Continuous Footing Excavation

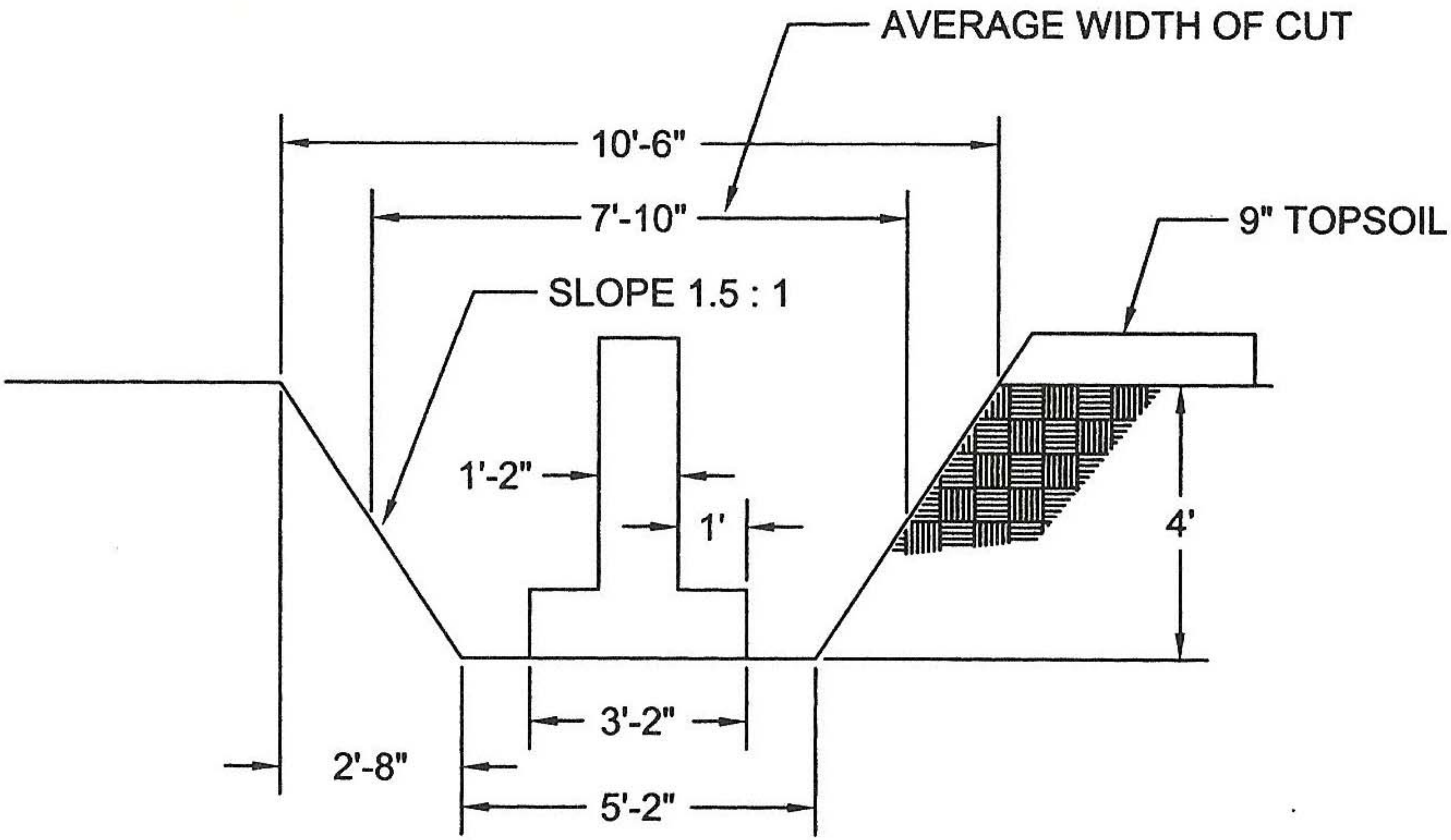


Figure 18 Continuous Footing Section

Problem 5 (continued) - Continuous Footing Excavation

Determining the amount of general excavation required for the continuous footings of the building shown in figure 15. Figure 18 is a sketch of the continuous footing with dimensions. In this example, the slope is 1.5:1, which means that for every 1.5 feet of vertical rise there is 1 foot of horizontal run.

The simplest way to approximate the amount of cut is to multiply the average cut width times the perimeter of the building times the depth. From figure 9 in problem 4, the building perimeter is 340 feet. However, 32’4” of that perimeter was included in the basement wall (figure 15). Therefore, the linear distance of continuous footing is 307’8”.

General excavation (cf) = 7’10” x 307’8” x 4’

General excavation (cf) = 7.833’ x 307.67’ x 4’ = 9,640 cf

General excavation (cy) = 9,640 cf / 27 cf per cy = 357 cy

Problem 5 (continued) - Continuous Footing Excavation

Required equipment: Backhoe with .5 cy bucket
Mobilization: 2 hours
Rate of work for backhoe: 25 cy per hour
Equipment cost: $27.75 per hour
Operator cost: $39.75 per hour

Equipment hours = 357 cy / 25 = 14 hours
Total hours = 14 equipment hours + 2 hours for mobilization = 16 hours
Equipment $ = 16 hours x $27.75 per hour = $444
Labor $ = 16 hours x $39.75 per hour = $636.00

Problem 6 - Backfilling the Basement Walls

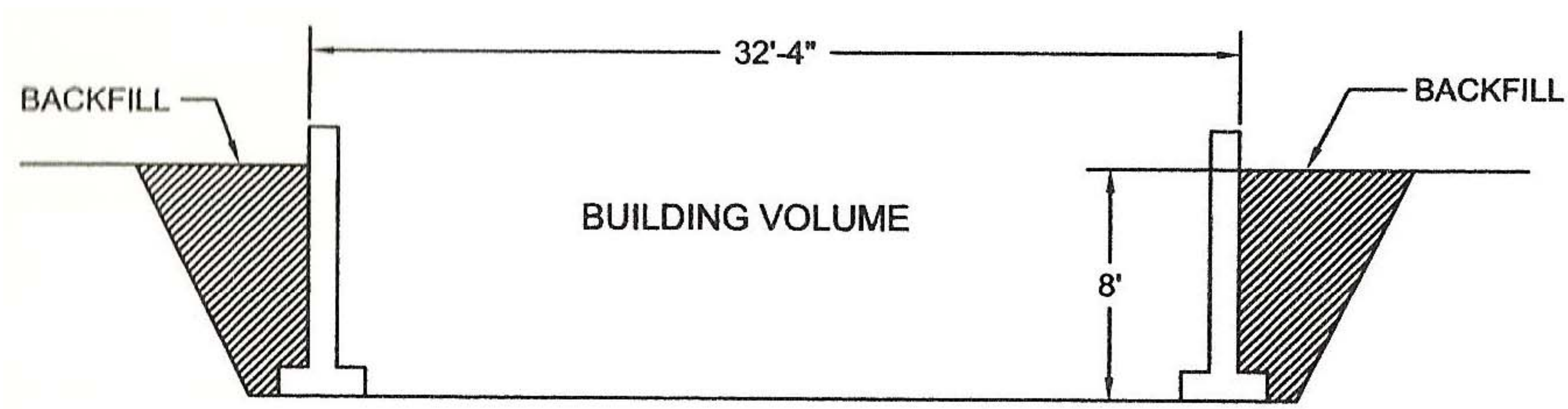


Figure 20 Backfill Section

Problem 6 (continued) - Backfilling the Basement Walls

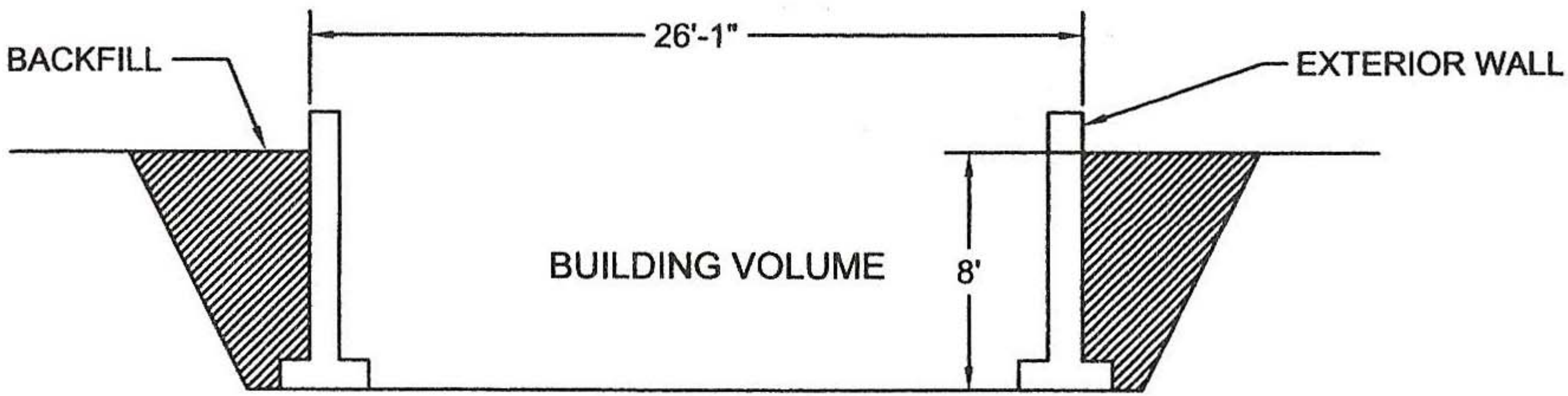


Figure 21 Backfill Section

Problem 6 (continued) - Backfilling the Basement Walls

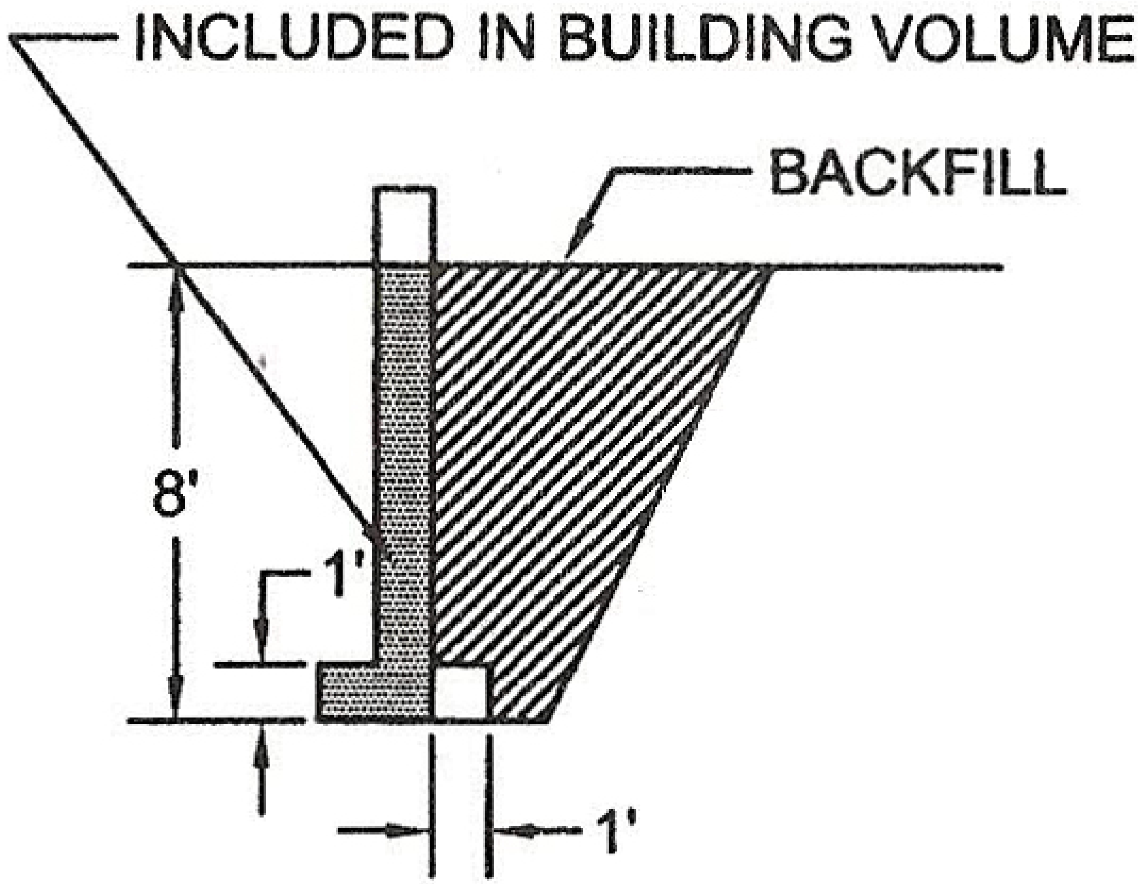


Figure 22 Footing Backfill

Problem 6 (continued) - Backfilling the Basement Walls

Using the sketches in figures 20, 21, and 22, the following volume calculations can be performed.

Building volume (cf) = 32’4” x 26’1” x 8’
Building volume (cf) = 32.33 x 26.083 x 8’ = 6,746 cf
Footing volume (cf) = 1’ x 1’ x 26’1” x 2
Footing volume (cf) = 1’ x 1’ x 26.083’ x 2 = 52 cf
Footing volume (cf) = 1’ x 1’ x 32’4” x 2
Footing volume (cf) = 1’ x 1’ x 32.33’ x 2 = 65 cf

From figure 15, the basement excavation is 11,024 cf
Backfill (cf) = 10,997 cf (General excavation) – 6,746 cf (Building volume)
-52 cf – 65 cf (Footing volume)
Backfill = 4,134 cf
4,139 cf / 27 cf per cy = 153 cy

Problem 6 (continued) - Backfilling the Basement Walls

Equipment: Dozer (120 hp) at $26.85 per hour
Dozer work rate: 100 cy per hour (figure 11)
Operator: $38.30 per work hour
Laborer: $18.50 per work hour
Mobilization: 1.5 hours

Backfill time (hrs) = 153 cy / 100 cy per hour = 1.5 hours
Total hours = 1.5 work hours + 1.5 mobilization hours = 3 hours
Operator cost ($) = 3 hours x $38.30 per hour = $114.90
Laborer cost ($) = 3 hours x $18.50 per work hour = $55.50
Equipment cost ($) = 3 hours x $26.85 per hour = $80.55

Problem 7 - Backfilling the Foundation Walls

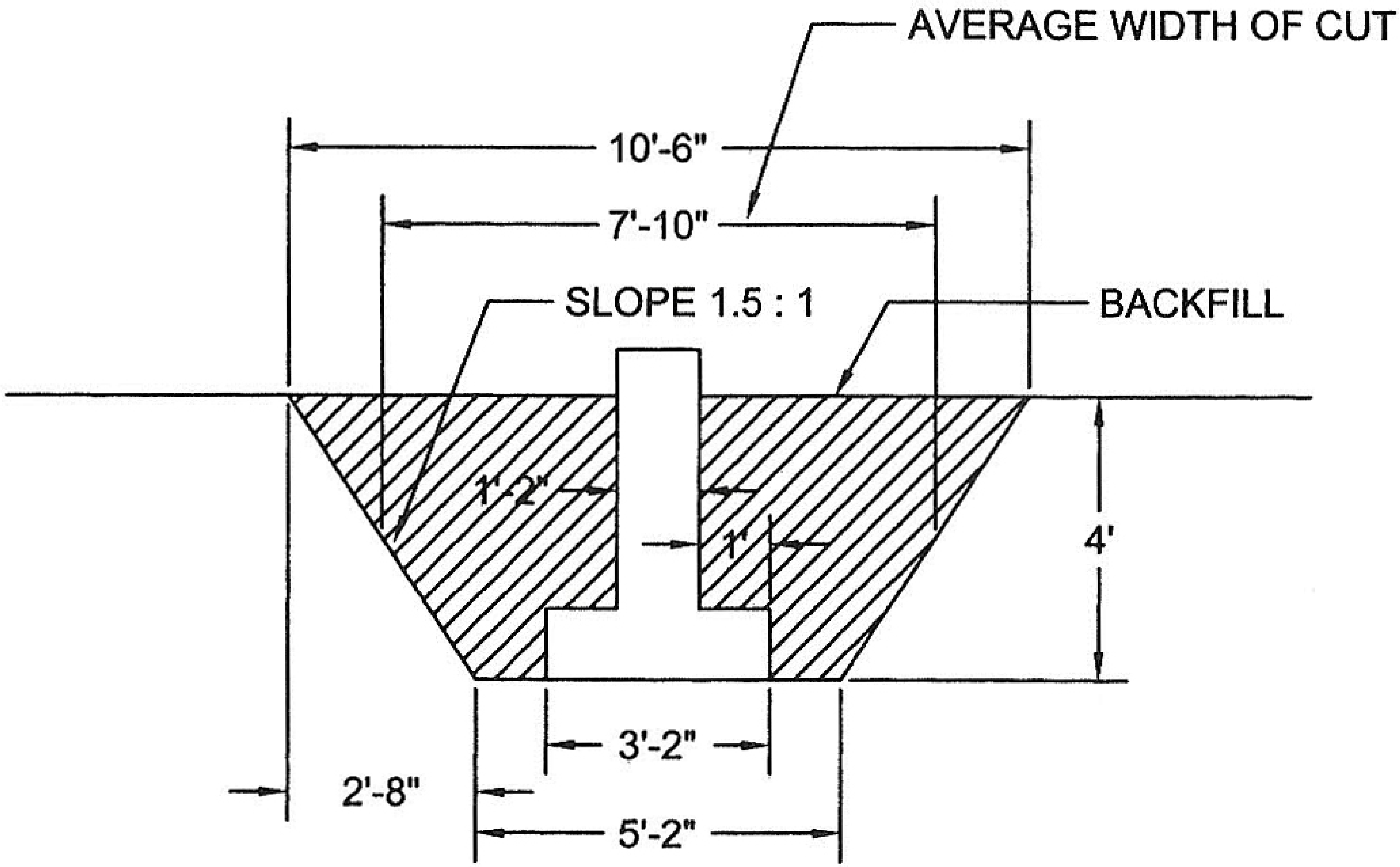


Figure 23 Continuous Footing Backfill

Problem 7 (continued) - Backfilling the Foundation Walls

There are two ways in which the quantity of backfill can be determined. Both will yield virtually the same answer. The first is to subtract the area of the footing from the area backfill and multiply that number by the length of the footing. Figure 23 is a sketch of the backfill requirements.

Volume of footing (cf) = 3’2” x 1’ x 307’8”
Volume of footing (cf) = 3.167’ x 1’ x 307.67’ = 974 cf
Volume in foundation wall (cf) = 3’ x 1’2” x 307’8”
Volume in foundation wall (cf) = 3’ x 1.167’ x 307.67’ = 1,077 cf
Volume in continuous footing (cf) = 874 cf + 1,077 cf = 2.051 cf
Volume of backfill = 9,640 cf – 2,051 cf = 7,589 cf

Problem 7 (continued) - Backfilling the Foundation Walls

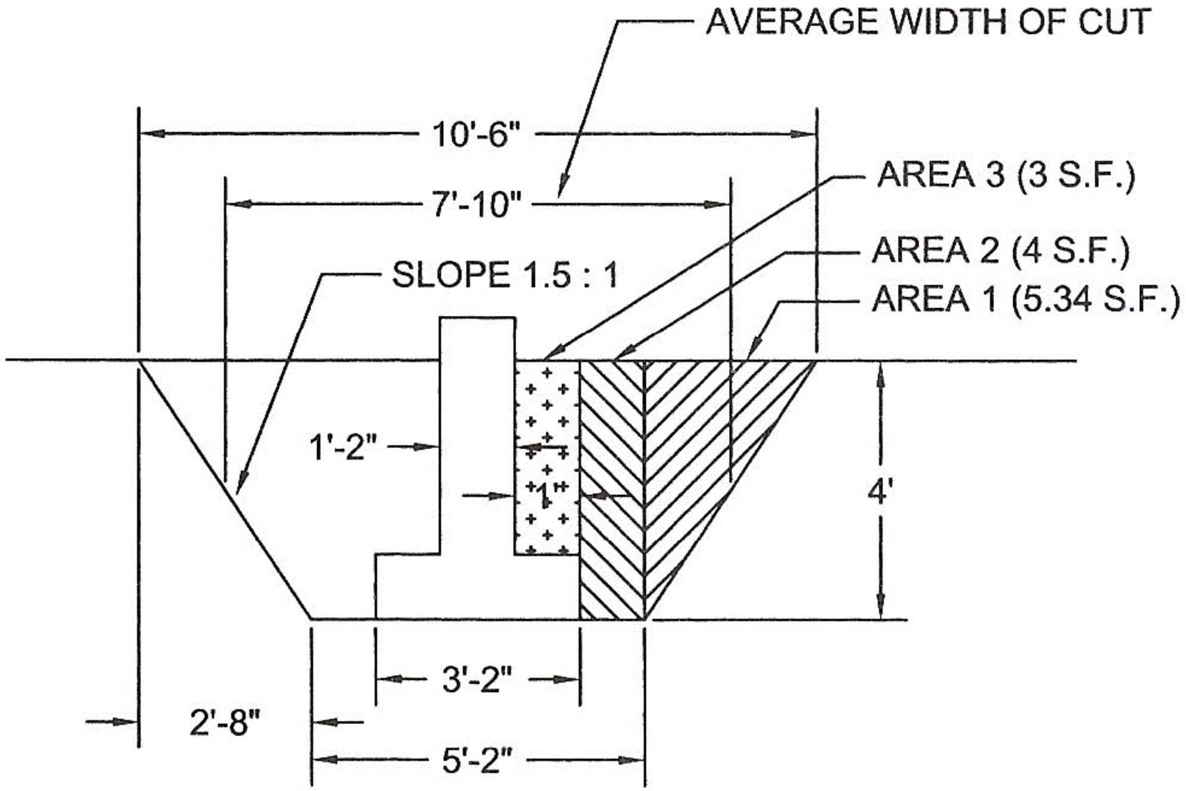


Figure 24 Alternate Backfill Method

Alternate Solution

Fill area (sf) = (5.34 sf + 4 sf + 3 sf) x 2 = 24.68 sf

24.68 sf x 307.67' = 7,593 cf

Problem 8 - Material Takeoff

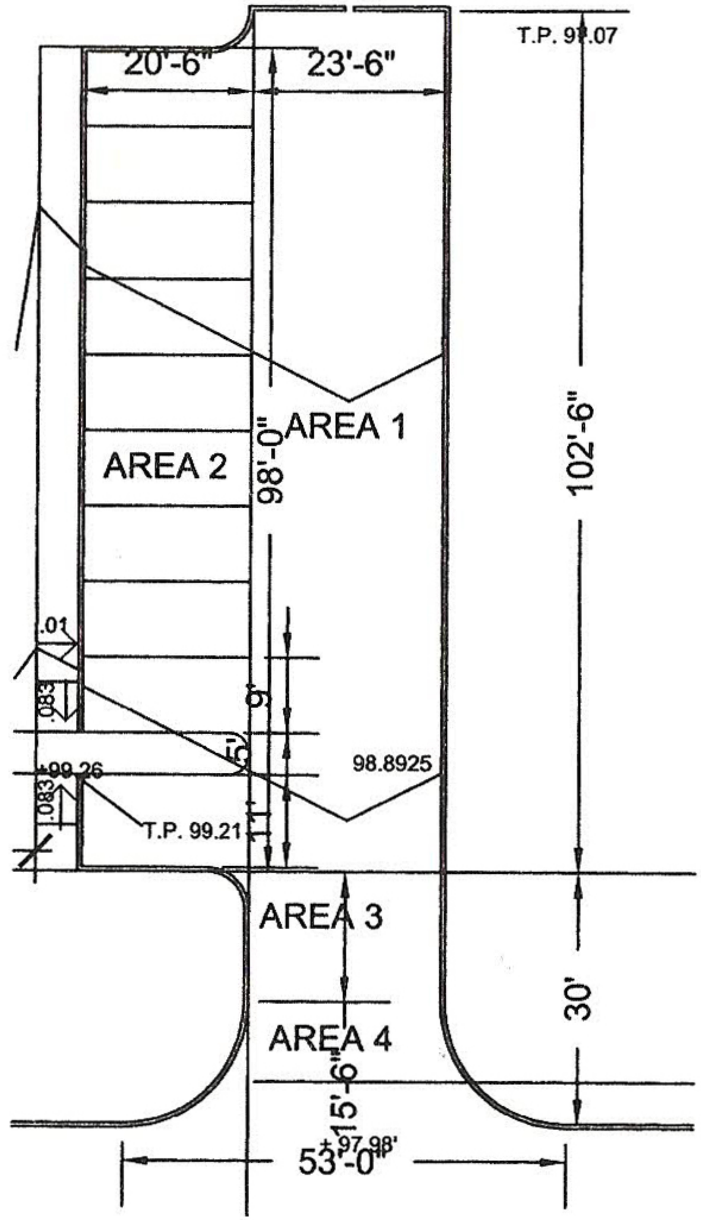


Figure 25 Parking lot

Problem 8 (continued) - Material Takeoff

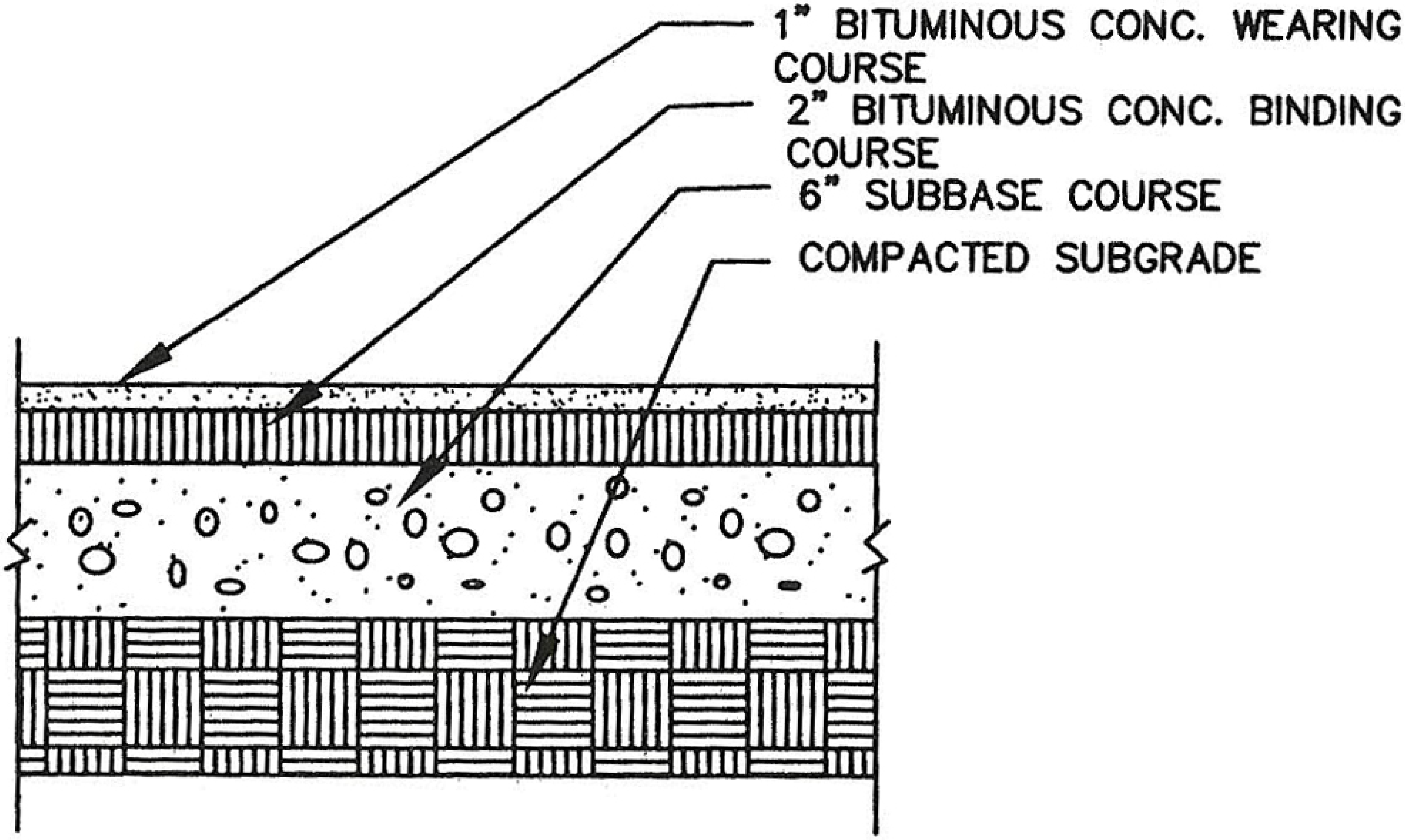


Figure 26 Parking lot section

Problem 8 (continued) - Material Take off Solution

Determine the quantity of asphalt and subgrade material required for the parking lot in the commercial building. Figure 25 is an excerpt of the parking lot while figure 26 is a cross section. Assume that the asphalt required is 3 inches thick and the subgrade is 6 inches thick.

Area 1 = 23.5’ x 102.5’ = 2,409 sf
Area 2 = 20.5’ x 98.0’ = 2,009 sf
Area 3 = 15.5’ x 23.5’ = 364 sf
Area 4 = ((53.0 + 23.5) x 14.5’) / 2 = 555 sf
Total area = 5,337 sf

Asphalt = 19.5 tons per 1,000 sf 3” thick x 5.3 thousand sf
Asphalt = 104 tons of asphalt

Subgrade material = 31.5 tons per 1,000 sf 6” thick x 5.3 thousand sf
Subgrade Material = 167 tons

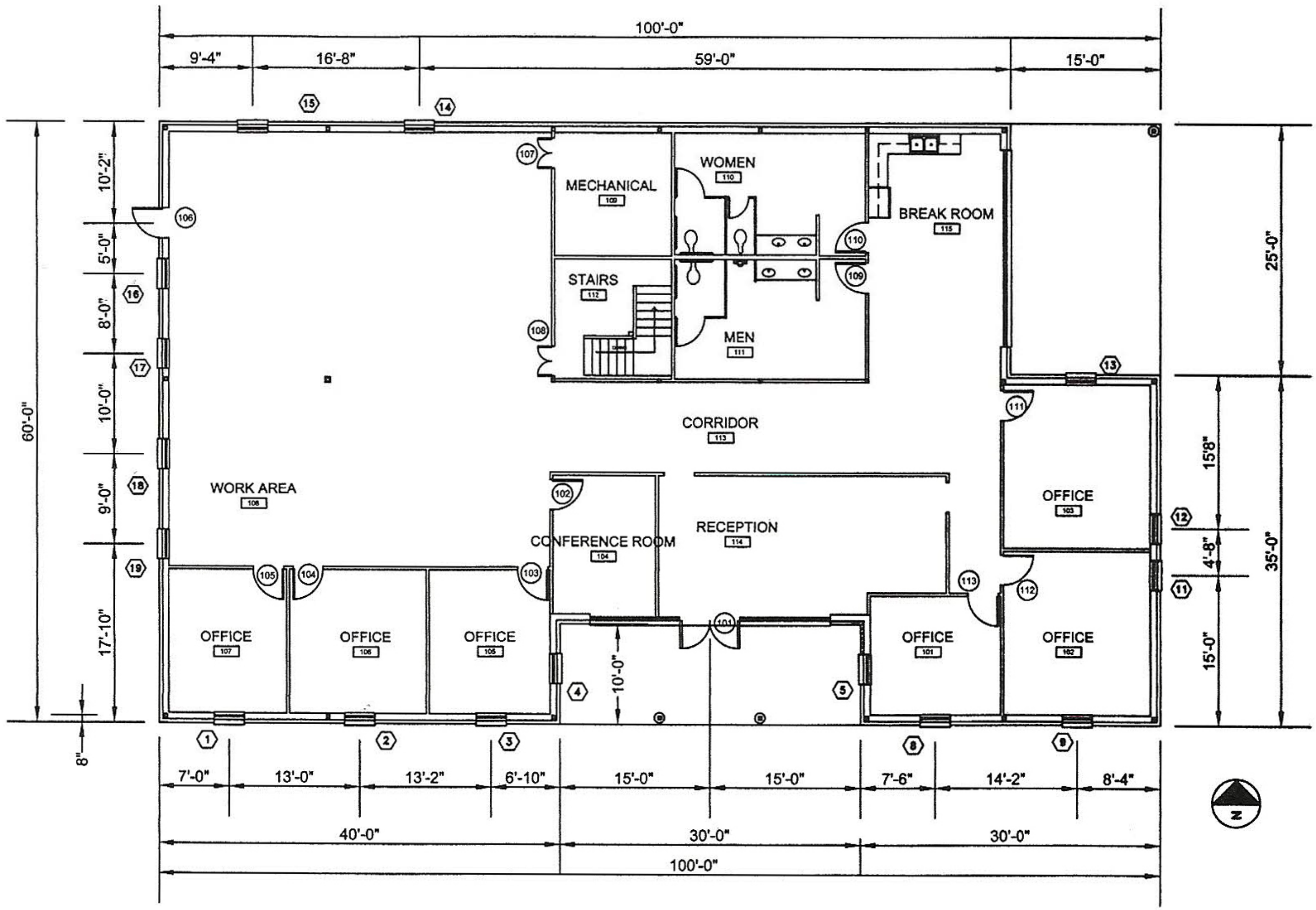
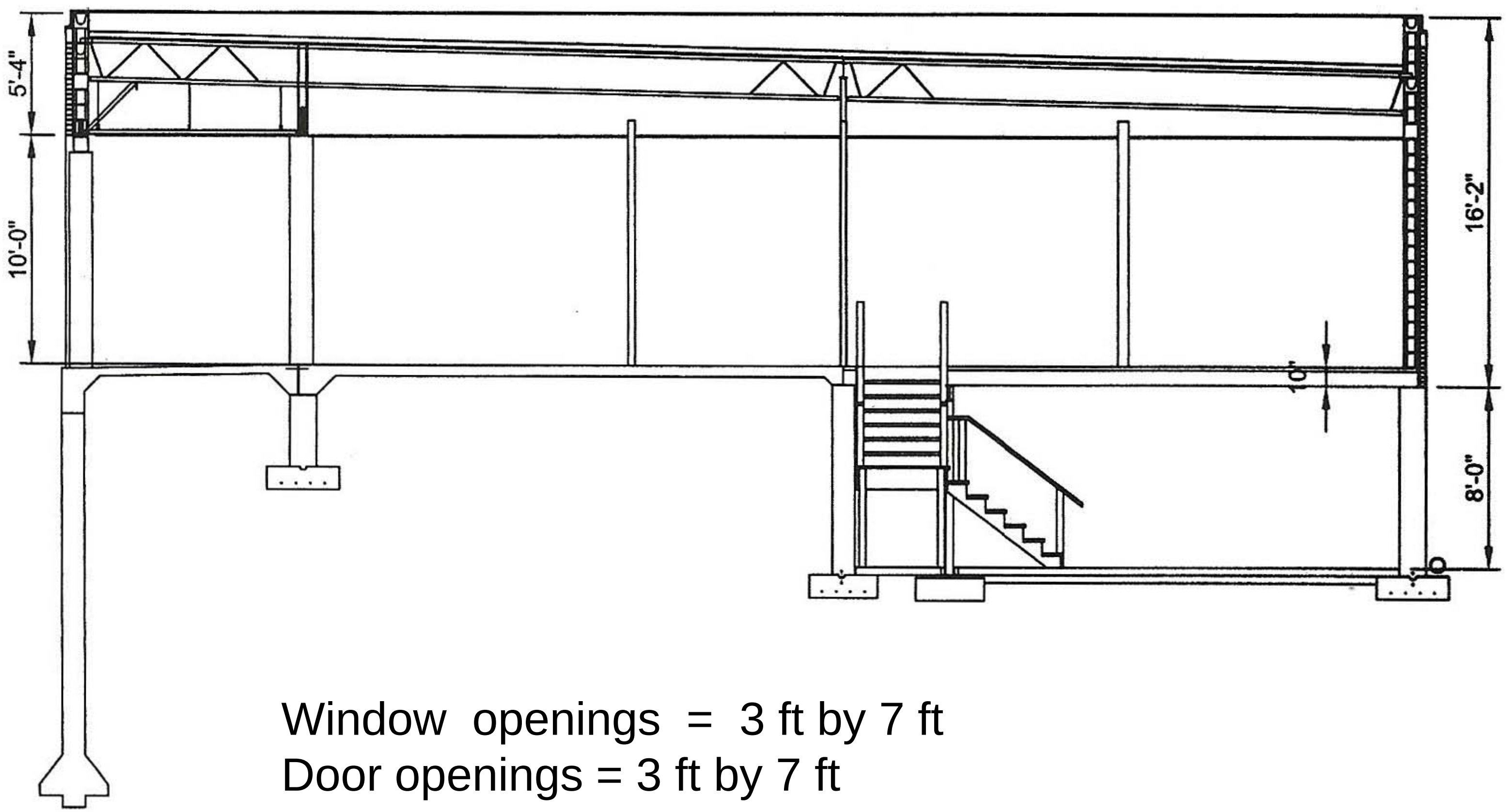


Figure 27 Building floor plan



Window openings = 3 ft by 7 ft
Door openings = 3 ft by 7 ft

Figure 28 Wall section

Problem 9 - Material Takeoff

Determine the quantity of concrete block required for the west wall of the small commercial building shown in Figures 27 and 28.

Wall height for concrete block = 16’2” – 10” = 15’4”
West wall length = 60’0” – 9” (both end brick ledge) = 59’3”
Gross wall area (sf) = 15’4” x 59’3”
Gross wall area (sf) = 15.33’ x 59.25’ = 908 sf

Problem 9 (continued) - Material Takeoff

Openings

Windows 4 @ 3’ x 7’ = 84 sf

Doors 1 @ 3’ x 7’ = 21 sf

Area of openings = 84 sf + 21 sf = 105 sf

Net west wall area = 908 – 84 – 21 = 803 sf

Using an 8” x 8” x 16” block = 1.125 blocks per sf

803 sf x 1.125 blocks per sf = 903 blocks

Waste @ 6% - use 958 blocks

Problem 9 (continued) - Material Takeoff

Header / Lintel Blocks

Top course = 59’3” / 16” = 45 blocks

Windows / doors = 4 per opening

5 openings = 20 blocks

Plain block = 958 – 45 – 20 = 893 blocks

For west wall purchase

893 – 8 x 8 x 16 blocks

65 header blocks

Work Hours per 100 Square Feet										
Wall Thickness	4"		6"		8"		10"		12"	
Workers	Mason	Laborer	Mason	Laborer	Mason	Laborer	Mason	Laborer	Mason	Laborer
Type of Work										
Simple Foundation					4.5-6.0	4.0-7.5	6.0-9.0	7.0-10.5	7.0-10.0	8.0-11.5
Foundation with several corners, openings					5.0-7.5	5.0-7.5	6.5-10.0	7.5-12.0	7.5-10.0	8.5-12.0
Exterior walls 4'-0" high	3.5-5.5	3.5-6.0	4.0-6.0	4.0-6.5	4.5-6.0	5.0-7.5	6.0-9.0	7.0-10.5	7.0-10.0	8.0-11.5
Exterior walls, 4'-0" to 8'-0" above ground or floor	3.5-6.0	4.5-7.5	4.0-6.5	4.5-7.0	4.5-6.5	6.0-9.0	6.5-10.0	7.5-12.0	7.5-10.0	8.5-12.0
Exterior walls, more than 8'-0" above ground or floor	4.5-8.0	6.0-9.5	5.0-9.0	7.0-10.0	5.0-7.0	7.0-10.0	7.0-10.5	7.5-12.0	7.5-10.0	8.5-12.0
Interior partitions	3.0-6.0	3.5-7.0	3.5-6.5	4.5-7.5	4.5-6.0	5.0-7.5				

Note:

1. The more corners and openings in the masonry wall, the more work hours it requires.
2. When lightweight units are used the work hours should be decreased by 10percent.
3. Work hours include simple pointing and cleaning required.
4. Special bonds and patterns may increase the work hours by 20 to 50 percent.

Figure 29 Work hours required for concrete masonry

Problem 9 (continued) - Material Takeoff

From figure 29 the work hours can be determined.

Using 6 mason work hours per 100 sf and 8 labor work hours per 100 sf

8.03 hundred sf x 6 = 48 mason work hours

8.03 hundred sf x 8 = 64 laborer work hours

Assuming a bare labor rate of $29.25 for masons and $18.00 for laborers per work hour, the bare labor costs can be determined.

Mason labor cost = 48 work hours x $29.25 per work hour = $1404.00

Laborer labor cost = 64 work hours x $18.00 per work hour = $1152.00

Total labor cost = $1404 + $1152 = $2556

Problem 10 - Reinforcing Bars

Please estimate the linear footage of reinforcing bars needed for the slab shown in figure 30. The bar spacing is 12 inches in both directions. The quantity of long and short bars needs to be determined. Figure 30 is an example of how the slab can be divided into unique areas so the quantity of reinforcing bars can be determined. Using area A as an example, the long bars will be (39’0” – 2”) 38’10” and the short bars would be (25’4” – 2”) 25’2”.

Long bar spaces = 25’4” / 12”
Long bar spaces = 25.33’ / 1’ – use 26 spaces
Add 1 to convert to bar count – use 27 bars
Short bar spaces = 39’0” / 12”
Short bar spaces = 39’ / 1’ = 39 spaces
Add 1 to convert to bar count – use 40 bars
Total length of long bars (lf) = 38’10” x 27 bars
Total length of long bars (lf) = 38.833’ x 27 bars = 1,049 lf
Total length of short bars (lf) = 1,049 lf + 1,007 lf = 2,056 lf
Total weight of bars (pounds) = 2,056 lf x .376 pounds per square foot
Total weight = 773 pounds
Add 10% for lap and waste – use 850 pounds

Problem 10 - Reinforcing Bars

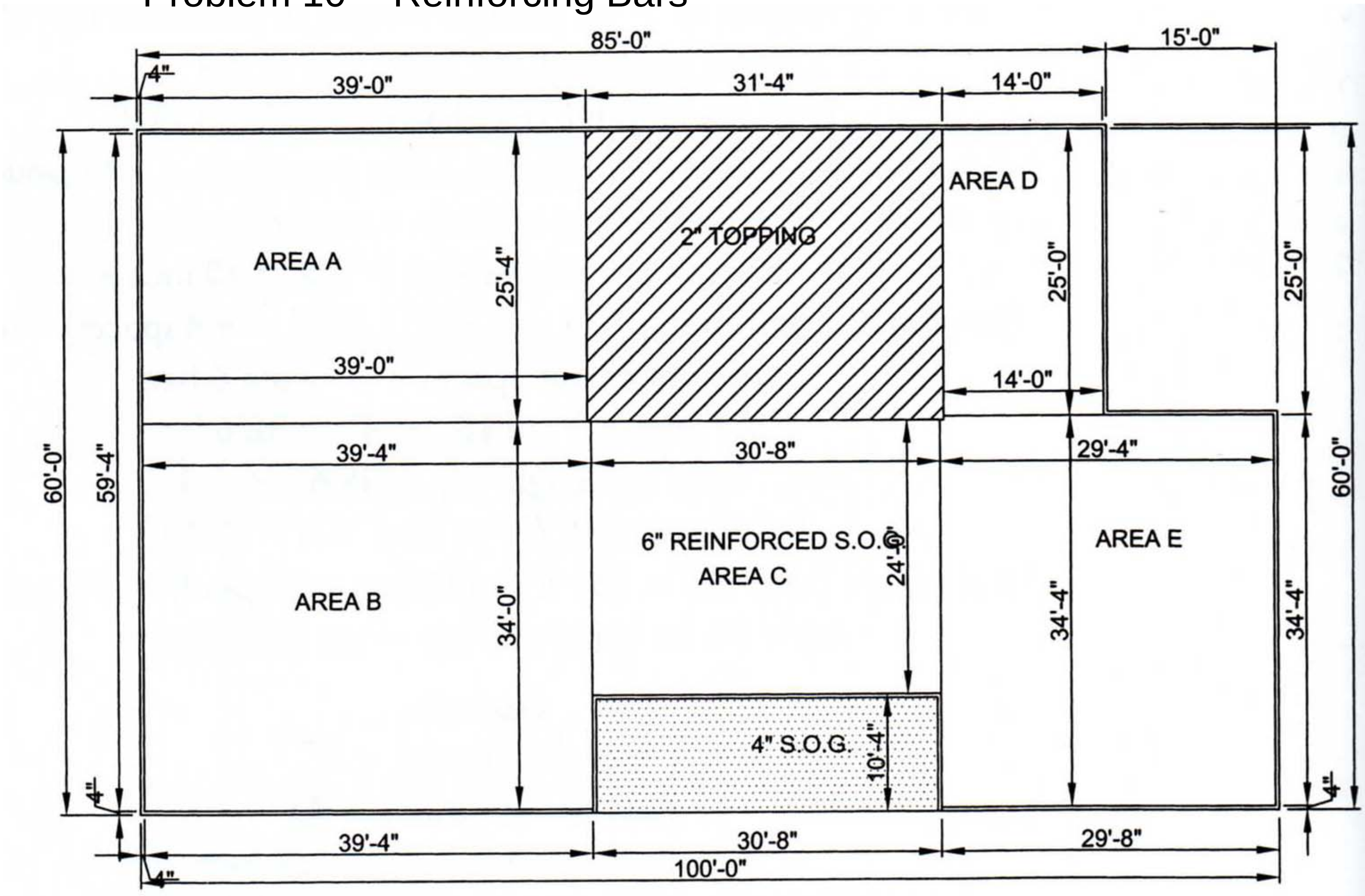


Figure 30 Reinforcing steel layout

References:

Collier, A.C.,Ledbetter,W.B., Engineering Cost Analysis, Harper and Row, Publishers, New York, 1982.

Dagostino, F. R., Feigenbaum,L., Estimating in Building Construction, Prentice Hall, New Jersey, 2003.

Thank you

and

Good Luck!