Lecture Seven

Mustansiriyah University / Faculty of Engineering

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Lecture Seventh

Overlay Design for Flexible Pavements

1.1 Need for Overlay

A flexible pavement, with accumulated traffic loads and time in service, may suffer one or more of the following deficiencies:

1. Excessive rutting
2. Excessive cracking
3. Inadequate ride quality
4. Inadequate skid resistance of surface

In some cases, a pavement may be adequately maintained and may not have the above-listed deficiencies, but the pavement may have the following problems:

1. Excessive maintenance costs.
2. Inadequate structural capacity for the expected future traffic loads.

In all of the above cases, treating the pavement with an overlay is the most commonly used method for restoring or upgrading the pavement to its desired condition and level of serviceability.

1.2 Types of Overlay for Flexible Pavements

The types of overlay on flexible pavements include the following:

1. Asphalt concrete overlay on flexible pavement
2. Conventional Portland cement concrete overlay on flexible pavement, in which the concrete layer is placed unbonded over the asphalt surface.
3. Ultra-thin Portland cement concrete overlay on flexible pavement, in which a thin concrete layer of 10 cm (4 in.) or less is placed bonded over the asphalt surface.

1.3 Overlay Design Procedure

Overlay design procedures that have been used can be grouped into three main categories as:

1. Component analysis design,
2. Deflection-based design, and
3. Analytically-based design.

A **component analysis overlay design** procedure basically involves evaluating the condition of the components (pavement layers) in the existing pavement to be overlaid, and comparing them to equivalent thicknesses of new pavement materials to be placed. The required overlay thickness is equal to the difference between the required total thickness and equivalent thickness of the existing layer. The procedure usually requires making an engineering judgment based on visual inspection and laboratory testing of the existing pavement materials.

Examples of component analysis overlay design procedures include (1) AASHTO, 1993 component analysis overlay design procedure (AASHTO, 1993), (2) Asphalt Institute effective thickness method (Asphalt Institute, 2000), and (3) U.S. Corps of Engineers component analysis method (Corps of Engineers, 1958).

A **deflection-based overlay design** procedure basically uses the surface deflection caused by a nondestructive test (NDT) to estimate the structural capacity of an existing pavement. The required overlay thickness is the additional pavement thickness that will be required to bring the NDT deflection to the desired level. This type of design procedure is usually based on the empirical correlations between certain NDT deflections and field performances.

- Because of the empirical nature of this procedure, the applicability of a particular procedure is usually limited to regions of similar conditions (such as, climate, soil type and pavement materials used), and the same NDT test procedure used.

Examples of deflection-based overlay design procedures include

(1) Asphalt Institute deflection-based method (Asphalt Institute, 2000),

(2) California Department of Transportation method (Caltrans, 1995),

(3) AASHTO, 1993 deflection-based overlay design procedure (AASHTO, 1993),

(4) Transport and Road Research Laboratory (U.K.) method (Lister et al., 1982),

(5) Roads and Transport Association (Canada) method (CGRA, 1965), and

(6) U.S. Army Corps of Engineers deflection-based method (Hall, 1978).

An **analytically based (or mechanistic) overlay design** procedure is based on the analysis of stresses and strains in a pavement due to the expected traffic loads, and the correlations of the analytical stresses and strains to performance. The required overlay thickness is the additional pavement thickness that will be required to bring the expected stresses and strains to the acceptable levels to prevent failure.

- This procedure requires extensive evaluation of the in-situ properties of all the materials to be used in the pavement structure, including their damage characteristics (such as, creep and fatigue behavior.)
- This procedure also requires more extensive analysis as compared with the other two methods.

Examples of analytically based AC overlay design procedures include (1) Federal Highway Administration (FHWA) procedure developed by Austin Research Engineers (ARE) (ARE, 1975), (2) FHWA procedure developed by Resource International Incorporated (RII) (Majidzadeh and Ilves, 1980), (3) Shell Research Procedure (Claessen and Ditmarsch, 1977), (4) Washington DOT Everpave method (WSDOT, 1995), (5) University of Nottingham (U.K.) method (Brown et al., 1987), (6) Austroads method (Austroads, 1994), and (7) Florida REDAPS procedure (Ruth et al., 1990).

2. Evaluation of Pavement Performance for Overlay

In designing an overlay for an existing pavement, it is imperative to perform a thorough evaluation of the existing pavement to determine its areas of deficiency and deterioration. The causes of the deficiencies and/or deterioration need to be determined so that the proper pretreatments and materials for use in overlay can be selected.

2.1 Functional Performance

The **functional performance** of a pavement is the ability of the pavement to serve its users in its primary function, which is to provide a **safe** and **smooth** driving surface.

- The most commonly used measure of functional performance of a pavement is its **ride quality**, which is commonly quantified in terms of **Present Serviceability Rating (PSR**), **Present Serviceability Index (PSI**), **Riding Comfort Index (RCI**), and **Ride Number (RN**).

- **Roughness** is commonly quantified in terms of the **International Roughness Index (IRI**). The concept of **PSR** and the standards for PSR were developed during the AASHO Road Test (Carey and Irick, 1960).

- **PSR** is a rating of pavement serviceability on a scale of zero (worst condition) to five (best condition), and is based on the average rating from a panel of 12 raters.

- At the time of the AASHO Road Test, a PSR of less than 2.5 was considered to be unacceptable for primary highways, and a PSR of less than 2.0 was considered to be unacceptable for secondary highways.

- The concept of **PSI** was also developed during the AASHO Road Test.

- Since it was not practical to have a panel of 12 raters, who needed to be calibrated to the original AASHO standards, to rate pavements at all times, a relationship between PSR and some measured physical characteristics for flexible pavements was developed as follows:

$$PSR = 5.03 - 1.91 \log_{10}(1 + \overline{SV}) - 1.38\overline{RD}^2 - 0.01\sqrt{C + P}$$

where:

$\overline{SV}$ = average slope variance in units of 10^{-6}.
$\overline{RD}$ = average rut depth in inches.
$C + P$ = cracking and patching in $ft^2/1000\ ft^2$.

<u>The estimated PSR obtained from the measured physical characteristics is termed PSI.</u> Of the three physical characteristics used in the prediction of PSR, the slope variance is the most dominant factor, and can be used to estimate PSR alone. Slope variance is a measure of longitudinal surface roughness. Various equipment for measuring pavement roughness have been used for determination of PSI.

2.2 Structural Performance

Structural performance of a pavement is its ability to sustain the applied traffic loads without showing distress. Deficiencies in a pavement's structural performance can be manifested through its observed distresses.

- Evaluation of pavement distresses is usually done through a **condition survey**, which is conducted by a **trained personnel** making visual observation of the rated pavement and noting down the **type, frequency and severity** of the observed distresses.

- **The three main types of distresses are:**

  (1) cracking,

  (2) rutting, and

  (3) raveling.

- The observed distresses can be used to determine the extent and the causes of deterioration in the pavement, and to determine the most appropriate pretreatments and materials to use for an overlay.

- The structural capacity of an existing pavement can be evaluated by performing a **component analysis**, or by means of **nondestructive testing**.

- From a **component analysis**, the **structural number** (SN) as used in the AASHTO, 1993 Pavement Design Guide (AASHTO, 1993 can be estimated.

- The measured deflections from NDT tests can be used to estimate the structural capacity of the pavement, based on the empirical relationship between certain NDT deflections and performance.

- They can also be used to back-calculate elastic moduli of the various layers in the existing pavement, which in turn can be used as inputs to analytical models to predict the behavior and performance of the pavement under various loading conditions.

2.3 Safety Performance

Two main common concerns in the evaluation of pavement safety are

(1) the skid resistance of pavement surface under wet condition, and

(2) the potential for hydroplaning.

- * The pavement surface's skid resistance under wet condition is commonly measured by the Locked Wheel Skid Trailer Test, which is standardized by ASTM as E274 Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Size Tire (ASTM, 2003). This test measures the skid resistance as experience by a locked tire traveling at 40 mi/h (64.4 km/h) on a wet pavement surface.

- Measurements of skid resistance are made in terms of **skid number** (SN40), which is defined as:

$$SN = 100\,f$$

where:

f = friction factor, or coefficient of friction as measured by this test.

- A skid number of over 35 on a wet surface is generally considered to be acceptable, while a skid number of less than 25 is considered unacceptable.
- **Hydroplaning** is the condition when the vehicle tires loss contact with the pavement surface due to the accumulation of water on the pavement surface.
- This can be caused by excessive rutting and/or insufficient cross slope in the pavement, which can cause accumulation of water on the pavement surface.
- A rut depth of 0.5 in. (10 mm) or more can create a potential for hydroplaning.
- The absence of an open-graded friction course on the pavement surface also increases the potential for accumulation of water and thus the potential for hydroplaning.

2.4 Selection of Pretreatments and Materials for Overlay

In the design and placement of an overlay for an existing pavement, it is very important that the causes of problems or deficiencies in the existing pavement should be determined and sound engineering judgment made in order to achieve effective benefits from the overlay. This section describes the recommended pretreatments and overlay materials for various conditions of the existing asphalt pavement to be rehabilitated.

2.4.1 Pavement with Extensive Cracking

If an existing pavement is severely cracked, it is important that the cracked layer should be milled off, or a crack relief layer such as an asphalt rubber membrane interlayer (ARMI) be placed before the overlay is placed, to prevent reflective cracking through the overlay. While it is possible to design a thicker overlay to postpone the time for reflective cracking to propagate to the surface, this approach is usually not cost effective unless an increase in the elevation of the pavement surface is needed.

2.4.2 Pavement with Top-Down Cracking

If an existing pavement suffers from top-down cracking, simply milling off the cracked layer and overlaying it with the same asphalt mixture will lead to the same problem again. Unlike bottom-up cracking, top-down cracking is not related to the thickness design of the pavement, but rather, to the material characteristics of the asphalt mixture used and the high surface stresses induced by the high pressure radial tires. These high surface stresses are not governed by the thickness of the asphalt layer. Asphalt mixtures with higher fracture energy (i.e., the amount of energy required to fracture the material) have been found to resist top-down cracking better. To reduce the potential for top-down cracking in this pavement in the future under the same traffic condition, the pavement needs to be over laid with an asphalt mixture which has demonstrated to be resistant to top-down cracking in service. This may require the use of a polymer modified asphalt mixture for the overlay, or placing a polymer modified interlayer between the friction course and the structural layer.

2.4.3 Pavement with Low-Temperature Cracking

Evenly spaced transverse cracks in asphalt pavements are low-temperature cracks caused by rapid cooling of the pavement surface coupled with the use of an asphalt mixture that is too hard at the low temperature. These cracks initiate from the surface and usually propagate to the bottom of the asphalt layer. If the asphalt layer is not to be removed, a crack relief layer may be placed on top of this pavement before the overlay is placed to prevent the cracks to reflect through the overlay. The same mixture with low-temperature cracking problem should not be used as the overlay material.

2.4.4 Pavement with Severe Rutting

If an existing pavement suffers from severe rutting, the pavement needs to be milled off to sufficient depth to remove the rut before the overlay is placed so that overlay will be of uniform thickness. If rutting occurred because of a rut susceptible mixture, the entire layer containing this unstable mixture needs to be milled off. The rut susceptible mixture should not be used as the overlay material.

2.4.5 Pavement with Insufficient Cross-Slope

If an existing pavement has insufficient cross-slope, resulting in inadequate drainage, sufficient pavement surface material must be milled off to correct the cross-slope before the overlay is placed.

2.4.6 Pavement with Raveling Problem

If an existing pavement has a raveling problem due to moisture damage on the surface, the deteriorated material needs to be milled off, and the existing drainage problem needs to be corrected before an overlay is placed. A stripping-resistant mixture needs to be used as the overlay material.

2.4.7 Pavement with Unstable Base or Subbase

If an existing pavement has an unstable granular base or subbase layer due to water saturation, the unstable layer needs to be removed and replaced with a stable material. If the problem is due to high water table, the water table needs to be brought down by installation of a properly designed sub-drainage system.

2.4.8 Pavement with Poor Ride Quality

If an existing pavement has a poor ride quality, but has sufficient structural capacity from its thickness design, the pavement should be milled to sufficient levelness, and an overlay of minimum required thickness may be placed to restore the pavement's ride quality.

2.4.9 Pavement with Poor Skid Resistance

If an existing pavement has inadequate skid resistance at the surface, the existing friction course, if any, needs to be milled off, and a new friction course may be placed as an overlay to restore the skid resistance of the pavement surface.

2.4.10 Proper Selection of Overlay Materials and Friction Courses

A lot of pavement distresses are related to quality of the materials rather than the pavement's thickness design. Thus, it is very important that proper asphalt mixtures with adequate cracking, rutting and stripping resistance be used as the overlay material. The asphalt binders used for the asphalt mixtures should be of a grade that is suitable for the expected environmental condition. If a structural overlay is placed on a high-volume high-speed highway, an appropriate friction course should be placed on the pavement surface to provide sufficient skid resistance.

3 Procedures for Design of AC Overlay on Flexible Pavement

3.1 AASHTO, 1993 Pavement Design Guide

The procedure for design of AC overlay on flexible pavement in the AASHTO, 1993 Pavement Design Guide (AASHTO, 1993) consists of a component analysis method and a deflection-based analysis method. It is based on the concept that the structural capacity of a flexible pavement can be quantified by a SN. The required overlay thickness is the amount that will increase the effective SN of the existing pavement (after the necessary milling and repair before the overlay) to the required SN to meet the future traffic demand. The relationship between the required overlay thickness and the other parameters can be expressed by the following equation:

$$SN_{ol} = a_{ol} D_{ol} = SN_f - SN_{eff}$$

where:

SN_{ol} = required overlay structural number.
a_{ol} = structural coefficient for the AC overlay.
D_{ol} = required overlay thickness in inches.
SN_f = required structural number for future traffic demand.
SN_{eff} = effective structural number of the existing pavement to be overlaid.

The procedures for determination of SN_{eff}, SN_f, aol and D_{ol} are described in the following sections.

3.1.1 Determination of Effective Structural Number of Existing Pavement (SNeff)

The effective structural number of an existing pavement to be overlaid (SN_{eff}) may be determined from (a) results of Non-Destructive Tests (NDT) (using a deflection-based procedure), (b) results of condition survey (using a component analysis), or (c) remaining life analysis.

3.1.1.1 Determination of SN_{eff} from NDT

The determination of SN_{eff} from results of NDT is based on the assumption that the structural capacity of a pavement is a function of its total thickness and overall stiffness. The relationship between SN_{eff}, thickness and stiffness as given in the AASHTO, 1993 Pavement Design Guide is as follows:

$$SN_{eff} = 0.0045 D \sqrt[3]{E_p}$$

where:

D = total thickness of all pavement layers above the subgrade in inches.
E_p = effective modulus of pavement layers above the subgrade in psi.

3.1.1.2 Determination of SN_{eff} from Condition Survey

The method of determination of SN_{eff} from condition survey involves making an engineering judgment in assigning layer coefficients and drainage coefficients to the various layers of the existing pavement, and calculating the SN_{eff} using the structural number equation as follows:

The assigning of drainage coefficients is similar to the case for new construction. Generally, the assigned layer coefficients of the in-service pavement materials should in most cases be less than the values that would be assigned to the same materials for new construction. However, limited guidance is available for the determination of layer coefficients for in-service pavement materials. Each highway agency usually adopts its own set of values to use based on local experience. The AASHTO, 1993 Pavement Design Guide provides a table with suggested layer coefficients for various pavement materials with various levels of deterioration. It is shown here as Table below.

3.1.2 Determination of Required Structural Number for Future Traffic (SN_f)

$$SN_{eff} = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

where:

D_1, D_2, D_3 = thickness of existing pavement surface, base and subbase layers.
a_1, a_2, a_3 = corresponding structural layer coefficients.
m_2, m_3 = drainage coefficients for granular base and subbase.

The determination of the required SN for future traffic for an overlaid asphalt pavement (SNf) is similar for a new construction. It requires the determination of (1) the future traffic (Nf), (2) the effective subgrade resilient modulus (MR), (3) the design PSI loss (ΔPSI), (4) design reliability (R), and (5) overall standard deviation (So).

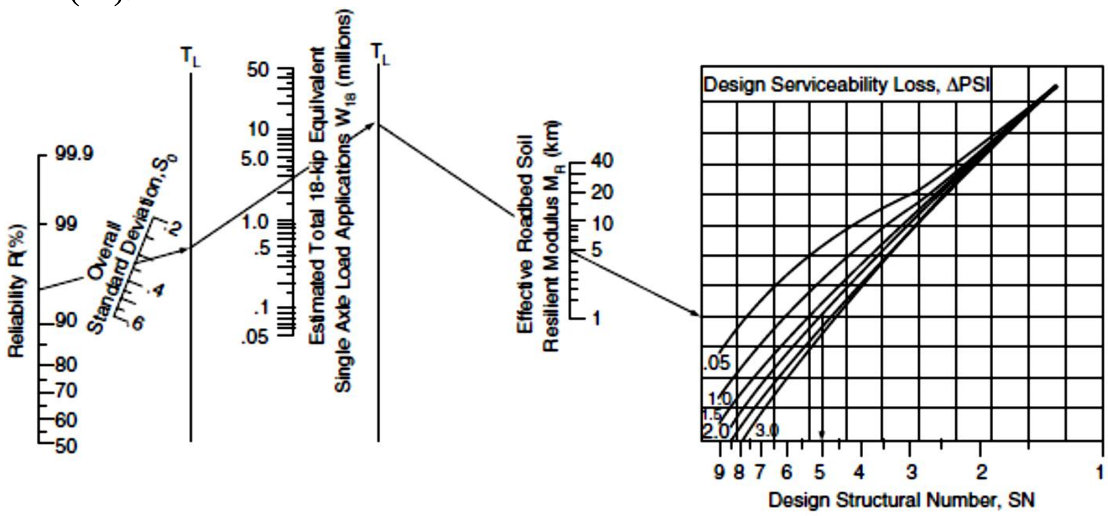

FIGURE 8.22 Design chart for flexible pavements based on using mean values for each input (AASHTO, 1993).

TABLE 11.1 Suggested Layer Coefficients for Existing AC Pavement Layer Materials

Material	Surface Condition	Coefficient
AC surface	Little or no alligator cracking and/or only low-severity transverse cracking	0.35–0.40
	<10% low-severity alligator cracking and/or <5% medium- and high-severity transverse cracking	0.25–0.35
	>10% low-severity alligator cracking and/or <10% medium-severity alligator cracking and/or >5–10% medium- and high-severity transverse cracking	0.20–0.30
	>10% medium-severity alligator cracking and/or <10% high-severity alligator cracking and/or >10% medium- and high-severity transverse cracking	0.14–0.20
	>10% high-severity alligator cracking and/or >10% high-severity transverse cracking	0.08–0.15
Stabilized base	Little or no alligator cracking and/or only low-severity transverse cracking	0.20–0.35
	<10% low-severity alligator cracking and/or <5% medium- and high-severity transverse cracking	0.15–0.25
	>10% low-severity alligator cracking and/or <10% medium-severity alligator cracking and/or >5-10% medium- and high-severity transverse cracking	0.15–0.20
	>10% medium-severity alligator cracking and/or <10% high-severity alligator cracking and/or >10% medium- and high-severity transverse cracking	0.10–0.20
	>10% high-severity alligator cracking and/or >10% high-severity transverse cracking	0.08–0.15
Granular base or subbase	No evidence of pumping, degradation, or contamination by fines	0.10–0.14
	Some evidence of pumping, degradation, or contamination by fines	0.00–0.10

Note: From Guide for Design of Pavement Structures, Volume I, 1993 by AASHTO, Washington, DC. With permission. Documents may be purchased from the AASHTO bookstore at 1-800-231-3475 or online at http://bookstore.transportation.org

3.1.3 Determination of Structural Coefficient for the AC Overlay (a_{ol}) and Required Overlay Thickness (D_{ol})

The required overlay thickness is computed as follows:

$$D_{ol} = \frac{(SN_f - SN_{eff})}{a_{ol}}$$

Example :

Initial serviceability, Po 4.2

Terminal serviceability, Pt 3.2

Reliability level, R 92%

Standard division, So 0.46

Performance period 20 years

Design Overlay Thickness

SN_f=SN_{eff}-(milling depth)*(a_1 of existing HMA)+ (a_{ol}*D_{ol})

SN_f= Structural number to carry future traffic

SN_{eff}= Structural number of the existing pavement

SN_{ol}= stracural number of the overlay=(a_{ol}*D_{ol})

a_{ol}= structural layer coffecient of the HMA overlay material

D_{ol}= Thickness of the HMA overlay, inch

Step1: Existing pavement

Thickness	Layer Material
3 inch	Bituminous surface course
8 inch	Bituminous base course
16 inch	Subbase
26 inch	Total

Step 2: traffic analysis

Initial AADT	30127
Final AADT	42628
CAR%	84
CARf	0.0008
LT%	8
LTf	0.163
HT%	8
HTf	1.655
Year	20
Days	365
DD%	58
DL%	90

Step 3: Condition Survey

Surface has extensive deterioration and raveling. There is 10% low severity alligator cracking and 5% medium severity transverse cracking.

Step 4: Deflection testing

Month	20000
January	20000
February	2800
March	4500
April	6500
May	7200
June	7600
July	5000
August	5000
September	7500
October	1000

November	18000
December	
Effective Mr	5000

Step 5: Coring and material testing

Back calculating material properties will be used to estimate existing material properties

Step 6: Determining required structural number for future traffic (SNf)

W_{18}=(AADTi+AADTf)/2*(Car%*Carf+LT%*LTf+HT%*HTf)*years*365

W_{18}= (1136+10000)/2*(84%*0.0008+8%*0.163+8%*1.655)*20*365

=5939655

Design ESALs (in design lane)

Design ESALs=Accumulated ESALs *D_D*D_L

= 5939655*0.58*0.9

= 3100300

Design Structural Number ,

Step7: determining effective stracural number of existing pavement, SN_{eff}

From FWD

Ep=120000 psi

D=26 inch

$$SN_{eff} = 0.0045D\sqrt[3]{E_p}$$

where:

D = total thickness of all pavement layers above the subgrade in inches.
E_p = effective modulus of pavement layers above the subgrade in psi.

SN_{eff}=5.77

From condition estimate

Thickness	Layer Material	Estimated layer Coefficient	Estimated SN
3 inch	Bituminous surface course	0.3	0.9
8 inch	Bituminous base course	0.35	2.8
16 inch	Subbase	0.08	1.28
			4.98

Use SN_{eff}=4.98

Step 8; Determining overlay thickness, (D_{ol})

Assume that a new overlay structural coefficient, a_{ol} =0.44

The project will be milled 2 inch. The existing HMA a_1=0.25

$SN_{ol}=SN_f-SN_{eff}$+(milling depth)*(a of existing HMA)

=6.0-4.98+(2)*(0.25)

=1.52

D_{ol}=1.52/0.44=3.45

=4 inch

Design Period, Years (n)	Annual Growth Rate, Percent (r)							
	No Growth	2	4	5	6	7	8	10
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
20	20.0	24.30	29.78	33.06	36.79	41.00	45.76	57.28
25	25.0	32.03	41.65	47.73	54.86	63.25	73.11	98.35
30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

**Factor =* $\frac{(1+r)^n - 1}{r}$, *where* $r = \frac{\text{rate}}{100}$ *and is not zero. If Annual Growth is zero, Growth Factor = Design Period.*