A practical
guide to

Low Volume Concrete Streets

for designers,
city engineers,
county engineers
and contractors

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Concrete Streets

Looking for value?

"It's unwise to pay too much, but it's unwise to pay too little. When you pay too much, you lose a little money; that is all. When you pay too little, you sometimes lose everything because the thing you bought was incapable of doing the thing you bought it to do. The common law of business prohibits paying a little and getting a lot – it can't be done. If you deal with the lowest bidder, it's well to add something for the risk you run.And if you do that, you will have enough to pay for something better."

—John Ruskin, 1819-1900 Author, Influential Critic, Philosopher

Value and longevity

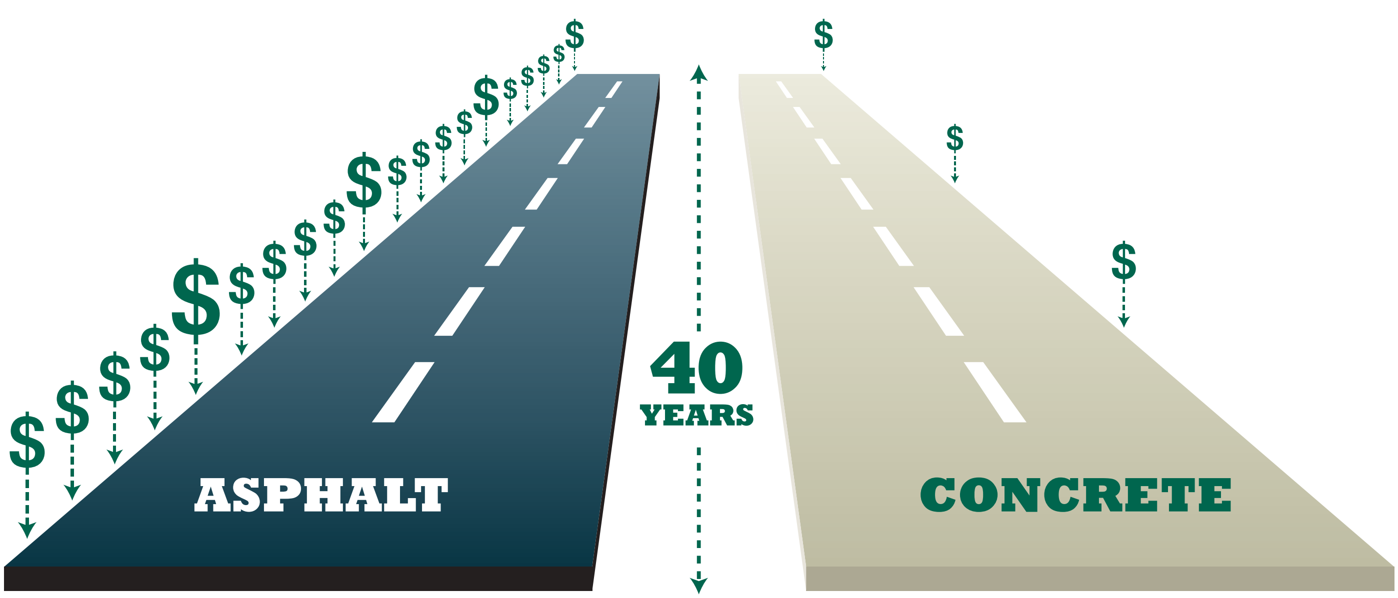
Concrete pavement has long been considered the most cost effective and sustainable pavement choice due to its ability to carry heavy traffic loads for long periods of time requiring only minimal routine maintenance and repairs over its performance life. Below is a figure that illustrates a typical city street construction and maintenance schedule for both concrete and asphalt pavements. As shown, asphalt pavements require almost continuous maintenance and overlay activities during the life of the pavement, with each activity consuming more materials and money. Each maintenance and rehabilitation activity likely also causes more traffic congestion.

Simple truths about life-cycle costs

Picture this. Two roadways are built with 40-year design lives. An asphalt road requires maintenance every 2 to 4 years and resurfacing every 8 to 14 years. The concrete road requires relatively little maintenance. Depending on usage, it may require some minor rehab every 12 to 16 years, but won't need to be resurfaced for 30, 40 or even 50 years.

Over time, the average asphalt pavement can cost up to **3 times more** than an equivalent concrete pavement. Rising crude oil and asphalt prices will make an asphalt pavement's life cycle cost even greater, and more unpredictable.

Because concrete pavements typically require little if any maintenance over their design life, the life cycle cost and life cycle sustainability of a concrete pavement is significantly lower than that of an asphalt pavement.



Thin Pavements Work! — Mn/Road

Portland cement concrete (PCC) pavements have served low-volume traffic applications very well for over 100 years. Unfortunately, due to higher initial construction costs often based on over-designed concrete pavements, and limited city and county construction budgets, the use of PCC pavements for low-volume roads was in decline. In response, the development of new mechanistic-empirical pavement design methods has demonstrated a renewed effort to characterize the load response behavior of all types of PCC pavements. With this new design method, we are able to provide a "thinner", lower cost PCC pavement. Test cell 32 at the Mn/Road test facility was constructed in June 2000 to study the behavior of a thin, low-cost PCC pavements, subject to heavy traffic loads and Minnesota's extreme weather conditions. Mn/Road test cell 32 is constructed of 5 inches (127mm) of jointed plain concrete over a 7 inch (178mm) thick layer of a Class 1 gravel base, a pumpable material. The subgrade layer is a silty-clay material, similar to many native soils around Minnesota.

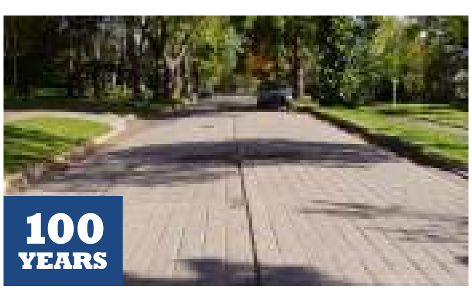
Lane widths are 12 feet (3.7m) and the slabs are 10 feet (3.1m) long and the transverse joints are undoweled and cut perpendicular to the centerline. The first of the two lanes on this section has been subject to an 80,000 lb. truck passing at 80 times per day @ 4 days per week. The second lane has been subject to 102,000 lb. passing at 80 times per day @ 1 day per week. This 5" pavement has withstood some very heavy loadings over a 10 year period with minimal signs of distress, far exceeding the expectations and requirements of typical low volume roads in Minnesota. Thin concrete pavements do work!

Thin Pavements at work in Minnesota

Below is a small representative sample of the many sensibly designed "thin" concrete pavements in service today found in many cities and counties throughout Minnesota.

City of Pipestone, Southwest Acres. This city street project spanned three blocks in a typical Minnesota residential neighborhood. The original bid included three pavement design alternates. The winning bid was for a 6" PCC pavement on 9" of Class 5 gravel on 8" of scarified and compacted subgrade. In considering the bids, the city determined that the additional cost (1 ½ %) for this concrete alternate would be far exceeded by the higher maintenance costs they would expect to incur if they accepted the lower asphalt bid. This concrete pavement was built and connected to an existing concrete street of similar design which has been in place for 20 years. This fact further reinforced their decision to go concrete!

City of Minneapolis, NE Tyler Street. The City of Minneapolis has over 150 miles of low volume concrete streets. Tyler Street & 36th Street in the City of St Anthony were built in 1968 in a residential neighborhood. These pavements were constructed of 6" concrete over 3" Class 5 base. The pavement width is 32 feet with transverse joints placed at 18' intervals. The concrete mix was Mn/DOT 3A31 with average compressive strengths of 3705 psi. Like many other low volume concrete streets of similar design and application in Minneapolis and throughout Minnesota, these pavements have received minimal maintenance over their service life while providing local government and taxpayers a durable and long-lasting street.



City of Duluth, East 7th Street. One of the oldest concrete streets in the United States can be found in the Chester Park neighborhood in Duluth. This residential street was built in 1910 and constructed of a patented concrete mix/process called Granitoid, a 2-layer, wet-on-wet concrete paving system. The street is distinguished by a basalt aggregate surface scored into rectangles imitating paver blocks. The road foundation was a 6" compacted base of "either clean black cinders or lake gravel". The base layer of concrete was a uniform 5 ¼" thick. The 1 ¾" top coat, called Granitoid Blocking", was to be applied before the base had begun to set. This historical street has served the local taxpayers well for an entire century. Despite some of the issues one might expect from a 100 year old pavement, East 7th Street is truly a testament to the longevity of Concrete!

Equivalent designs

This summary publication outlines recommended designs for the most typical low volume street sections in Minnesota.One key component of comparing pavements is developing equivalent designs. In this publication the equivalent designs were developed using the Mn/DOT State Aid Design Tables. These equivalent designs are based on soil conditions commonly found throughout Minnesota.

Preparing the subbase

A subbase, besides uniform support, provides other important functions such as pumping and faulting prevention, subsurface drainage, and a stable construction platform. For concrete slab design, the support from the subbase is considered negligible as the pavement load is carried primarily by the conrete slab (rigid design). In addition, this allows for a thinner total street section.

Composition and materials

Concrete pavement is constructed using ready mixed concrete manufactured locally from cement, high-quality aggregates and water. Chemical and mineral admixtures are also commonly used in concrete mixtures. Joint sealants, tiebars and load transfer devices may also be required in some pavement construction.The quality of the completed pavement is dependent upon the workmanship of the paving contractor and the quality of the concrete used in the project. Ready mixed concete for paving is normally specified in accordance with the requirements of ASTM C 94.

The specifier should:

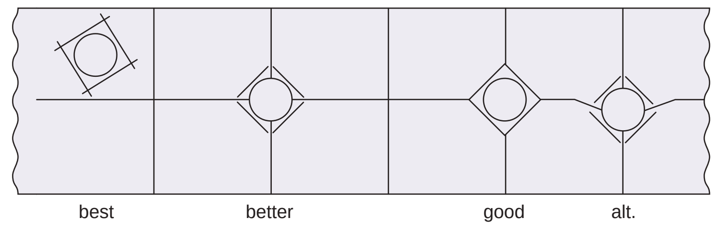
- Designate size of coarse aggregate (for paving generally 3/4”, 1”, or 1 1/2” maximum: but not greater than 1/4 the slab depth).
- Designate a maximum water cementitious ratio of 0.45.
- Designate slump (for paving 4” maximum).
- Designate air content of concrete to be (6.5% +/- 1.5%) per Mn/DOT Specification 2461.4A4b.

Jointing

Joints in concrete pavement aid construction and control the location and spread of cracks. Laying out joints requires good engineering judgment based on a few basic rules.

- Joint spacing should not exceed 30 times the pavement thickness. Pavements less than 6” thick should be jointed into 6’ x 6’ panels. Regardless of slab thickness, joint spacing should not exceed 15’.
- Lay out joints to form square panels. When this is not practical, rectangular joints can be used if the long dimension is no more than 1.25 times the short side.
- Control joints should be sawn to a depth of at least 1/4 the slab thickness (e.g., 1” for a 4” slab).
- Isolation (expansion) joints should extend the full depth and should be used only to isolated fixed objects abutting to or located within the paved area.
- Adjust jointing layout for location of manholes, catch basins, small foundations, and other built-in structures so that the joints will line up with the corners of the structures.
- Joint sealing - for pavements with a speed limit of 45 mph or less. Mn/DOT recommends a single cut, hot-pour sealant for both longitudinal and transverse joints

Manhole and drainage structures



- If a manhole or manholes fall on a joint line, then run joints to manhole as shown.
- It is recommended that the pavement designer use catch basins that are the same depth as the gutter.
- Compaction is critical. If there is improper compaction around pavement structures, the pavement will settle!
- When laying out joints, there are several things to consider regarding pavement structures. Please contact a concrete pavement specialist for assistance.

Construction practices

The choice of construction methods should be made by the contractor based on project size and available equipment. Once the type of equipment has been selected, a paving sequence and jointing plan should be developed to ensure smooth construction operations. On small jobs, the sequence of placing concrete is not critical, but on large projects it is usually best to place concrete in alternate lanes.

Other procedures that will ensure a quality job are:

- Slope pavement a minimum of 1% or 1/8” per foot for drainage.
- Moisten subgrade just prior to placement of concrete.
- For pavements, minimal finishing is needed. A bullfloat finish is adequate. A skid-resistant texture should be added with a broom, burlap drag or artificial turf drag.
- Curing freshly placed concrete will enhance concrete’s performance. A Mn/DOT approved liquid membrane-forming compound is usually recommended as the most cost-effective curing agent and should be applied immediately after finishing.
- Keep automobile traffic off the slab for three days and truck traffic off the slab for seven days or until conrete reaches a minimum opening compressive strength of 3,000 psi. High early strength concrete is available for earlier opening requirements.

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Pavement Design Using Soil Factors

from Mn/DOT State Aid Design Tools (http://www.dot.state.mn.us/stateaid/ProjDeliv/saprograms/design_tools/PvmntDesSoilFact.pdf)

Required Gravel Equivalency (G. E.) and concrete thickness for various Soil Factors (S. F.). ADT = Average Daily Traffic - ADT can be defined as all vehicle types. HCADT = Heavy Commercial Average Daily Traffic - HCADT can be defined as all vehicles except motorcycles, cars, and trucks. For new constuction or reconstruction use projected ADT. For resurfacing or reconditioning use present ADT. All units of G. E. and concrete are in inches. The thickness design method used for the concrete values in the table below assumed a concrete flexural strength of 600 psi.

Less than 400 ADT

7 ton bituminous			Concrete w/ edge support	
S. F.	Minimum bit. G. E.	Total G. E.	w/o dowels	w/ dowels
50	3.00	7.25	5.0	N/A
75	3.00	9.38	5.0	N/A
100	3.00	11.50	5.0	N/A
110	3.00	12.40	5.0	N/A
120	3.00	13.20	5.0	N/A
130	3.00	14.00	5.0	N/A

150-300 HCADT

9 ton bituminous			Concrete w/ edge support	
S. F.	Minimum bit. G. E.	Total G. E.	w/o dowels	w/ dowels
50	7.00	14.00	5.0	6.0
75	7.00	17.50	5.0	6.0
100	7.00	21.00	5.0	6.0
110	7.00	22.40	5.0	6.0
120	7.00	23.80	5.0	6.0
130	7.00	25.20	5.0	6.0

1100-1500 HCADT

9 ton bituminous			Concrete w/ edge support	
S. F.	Minimum bit. G. E.	Total G. E.	w/o dowels	w/ dowels
50	8.00	20.30	5.5	6.0
75	8.00	26.40	6.0	6.0
100	8.00	32.50	6.0	6.0
110	8.00	35.00	*	6.0
120	8.00	37.40	*	6.0
130	8.00	39.80	*	6.0

*dowels recommended

400-1000 ADT

7 ton bituminous			Concrete w/ edge support	
S. F.	Minimum bit. G. E.	Total G. E.	w/o dowels	w/ dowels
50	3.00	9.00	5.0	N/A
75	3.00	12.00	5.0	N/A
100	3.00	15.00	5.0	N/A
110	3.00	16.20	5.0	N/A
120	3.00	17.40	5.0	N/A
130	3.00	18.60	5.0	6.0

300-600 HCADT

9 ton bituminous			Concrete w/ edge support	
S. F.	Minimum bit. G. E.	Total G. E.	w/o dowels	w/ dowels
50	7.00	16.00	5.0	6.0
75	7.00	20.50	5.5	6.0
100	7.00	25.00	5.5	6.0
110	7.00	26.80	5.5	6.0
120	7.00	28.00	5.5	6.0
130	7.00	30.40	*	6.0

*dowels recommended

Type of material	G.E. factor
Plant-mixed bit spec 2350/2360	2.25
Plant-mixed bit – type 41, 61	2.25
Plant-mixed bit – type 31	2.00
Cold in-place rec./rubbilized PCC	1.50
Bit pavement reclamation	1.00
Aggregate base (Cl 5 & 6) 3138	1.00
Aggregate base (Cl 3 & 4) 3138	0.75
Select granular spec 3149.2B	0.50

Less than 150 HCADT

7 ton bituminous			Concrete w/ edge support	
S. F.	Minimum bit. G. E.	Total G. E.	w/o dowels	w/ dowels
50	7.00	10.25	5.0	N/A
75	7.00	13.90	5.0	N/A
100	7.00	17.50	5.0	N/A
110	7.00	19.00	5.0	N/A
120	7.00	20.50	5.0	N/A
130	7.00	22.00	5.5	6.0

600-1100 HCADT

9 ton bituminous			Concrete w/ edge support	
S. F.	Minimum bit. G. E.	Total G. E.	w/o dowels	w/ dowels
50	8.00	18.50	5.5	6.0
75	8.00	23.70	5.5	6.0
100	8.00	29.00	5.5	6.0
110	8.00	31.10	*	6.0
120	8.00	33.20	*	6.0
130	8.00	35.30	*	6.0

*dowels recommended

AASHTO soil class	Soil factor (S. F.) %	Assumed R-value
A-1	50-75	70-75
A-2	50-75	30-70
A-3	50	70
A-4	100-130	20
A-5	130+	—
A-6	100	12
A-7-5	120	12
A-7-6	130	10

Mn/DOT concrete design notes (from Mn/DOT State Aid Design Office)

- Minimum recommended concrete pavement thickness is 5" for low volume roads.
- All concrete pavements are assumed to have a minimum of 4" Class 5 paving platform. Local experience may dictate a thicker section of Class 5 for construction reasons. This will not affect the thickness of the concrete.
- Edge support consists of: tied curb & gutter, tied shoulder or widened lane.
- Add 1" to concrete pavement thickness if no edge support is used.
- A sand sub-base is not required but may enhance constructability. A sand sub-base will also reduce the probability of faulting.
- Pavements less than 6" thick should be jointed into 6' x 6' panels.
- Panel lengths should not exceed the panel width; i.e. 12'x12', 13'x13'. Joints in tied C&G and shoulders should match the pavement.
- Dowel bars are encouraged for use on higher traffic pavements, especially on poor subgrade soils. If dowels are not used in these instances, diamond grinding should be expected as a future maintenance operation.
- Minimum thickness for doweled concrete is 6" to ensure cover over the dowel bars.
- All dowels assumed to be 1" diameter and in the wheel paths, minimum.
- **All concrete pavements meet standards for 10-ton pavements**, they have been designed for varying HCADT. References to 7-Ton and 9-Ton are for comparative reasons only. MN Statute 169.87 Subd. 2 excludes portland cement pavements from seasonal load restrictions.
- Standard Plans and Plates for concrete pavement can be found at www.dot.state.mn.us/tecsup/splan/english.html#5-297.200 and www.dot.state.mn.us/tecsup/splate/english.html#1000e
- Special Provisions for concrete pavements can be found at www.mrr.dot.state.mn.us/pavement/concrete/specialprovisions.asp. These include all materials and mix design requirements.

Subgrade Soil Properties

Mn/DOT classification	Field Identification	Ribbon[1] Length (in.)	Rating	Possible Equivalent Classes				
				Mn/DOT Soil Factor	AASHTO	ASTM Unified	CBR	R-Value
Gravel (G)	Stones pass 75 mm sive, retained on 2 mm	0	Excellent	50 - 75	A-1	GP-GM	-	70 (assumed)
Sand (Sa)	Will form a cast when wet. Crumbles easily, 100% passes 2 mm sieve.	0	Good to excellent	50 - 75	A-1, A-3	SP-SM	14.1	70 (assumed)
Loamy Sand (Lsa)	Grains can be felt. Forms a cast when wet.	0	Good to excellent	50 - 75	A-2	SM, SC	7.2	50 - 70
Sandy Loam (SaL) slightly plastic (< 10% clay)	Slightly plastic. Sand grains seen and felt. Gritty.	0 - 0.75	Fair to good	50 - 75	A-2	SM, SC	4.3	20 - 60
Sandy Loam (SaL) plastic (10 - 20% clay)	Slightly plastic to plastic. Sand grains seen and felt. Gritty.	0.75 - 1.5	Fair	100 - 130	A-4	SM, SC	3.9	15 - 30
Loam (L)	Somewhat gritty, but smoother than SaL.	0.25 - 1.5	Fair	100 - 130	A-4	ML, MH	3.6	12 - 30
Silt Loam (SiL)	Smooth, slippery and velvety. Cloddy when dry. Easily pulverized.	0 - 1.5	Poor	120 - 130	A-4	ML, MH	3.1	10 - 40
Sandy Clay Loam (SaCL)	Somewhat gritty. Considerableresistance to ribboning.	1.5 - 2.5	Fair to good	100	A-6	SC, SM	3.8	15 - 30
Clay Loam (CL)	Smooth, shiny, moderate resistance to ribboning.	1.5 - 2.5	Fair to good	100	A-6	CL	3.4	10 - 20
Silty Clay Loam (SiCL)	Dull appearance, slippery. Less resistance to ribboning tha CL. Very plastic but gritty. Long, thin ribbon. 0% - 30% sand.	1.5 - 2.5	Poor	120 - 130	A-6	ML/CL	3.1	10 - 20
Sandy Clay (SaC)	Very plastic but gritty. Long, thin ribbon, 50 - 70% sand.	2.5 <	Fair	120 - 130	A-7	SC	-	10 - 20
Silty Clay (SiC)	Buttery, smooth, slippery Less resistance to ribboning than CL.	2.5 <	Poor	120 - 130	A-7	ML/CL	3.1	10 - 20
Clay (C)	Smooth, shiny when smeared, long thin ribbon or thread.	2.5 <	Fair	120 - 130	A-7	CL, CH	3.2	10 -20

Design example

(refer to shaded area in Mn/DOT State Aid Design table on previous page)

Requirements

- 9 ton capacity
- 300 - 600 trucks per day

Reported Soil Factor. R=20 per geotechnical report – equivalent Mn/DOT soil factor SF = **110** from table above

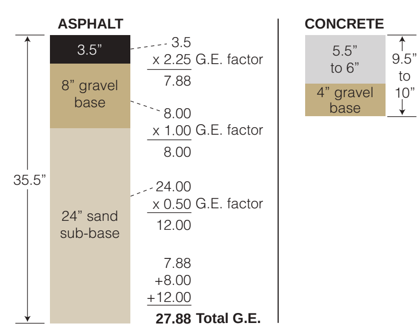
Step 1. Refer to Mn/DOT's State Aid Design Table on previous page and use the given criteria to determine the required G.E. (Gravel Equivalency). From the table:

Total G.E. required is = **26.8"** *and*
Minimum bituminous G.E. = **7"** *and*
Concrete: 5.5" w/o dowels, 6.0" w/ dowels

Step 2. To attain a minimum bituminous G.E. of 7.0"as required, 3.5" of asphalt is required yielding a **G.E. of 7.88"**. Assuming an average 8" gravel base will yield a **G.E. of 8.00"** atop of a 24" sand sub-base yielding a **G.E. of 12.00"**.

Step 3. Combine G.E. factors for each pavement section layer to achieve **Total G.E. = 27.88"**. Total G.E. calculated *meets and exceeds* minimum Requirement from design table.

RESULT. A 9.5-10.0" concrete section (10 ton pavement) has an equivalent G.E. as a 35.5" asphalt section



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Typical Street Sections

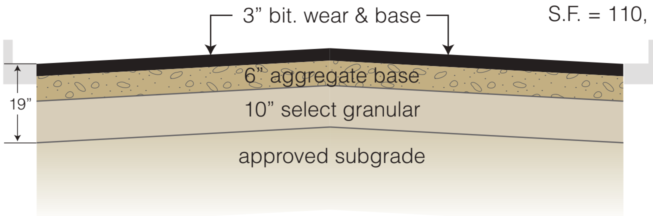
Based on Mn/DOT State Aid design tables.

7-ton design (design based on Average Daily Traffic)

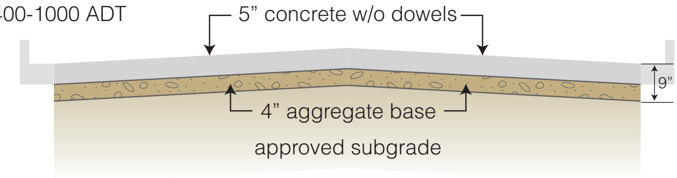
asphalt

Total G.E. = 17.75

S.F. = 110, Traffic = 400-1000 ADT



concrete

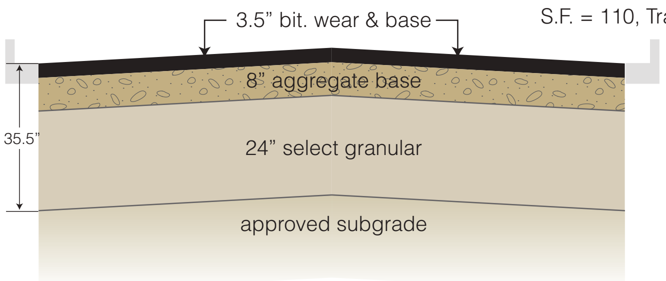


9-ton design (design based on Heavy Commercial Average Daily Traffic)

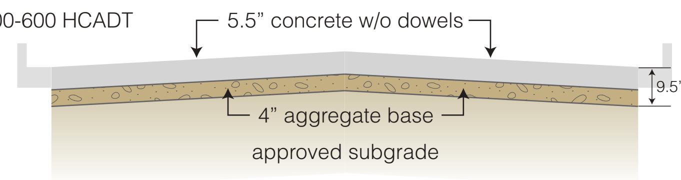
asphalt

Total G.E. = 27.88

S.F. = 110, Traffic = 300-600 HCADT



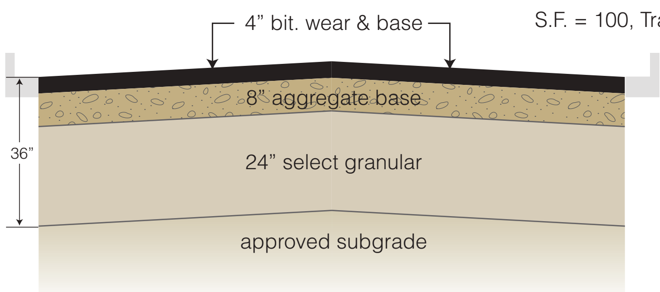
concrete



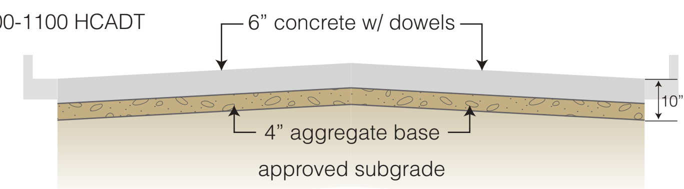
asphalt

Total G.E. = 29.00

S.F. = 100, Traffic = 600-1100 HCADT



concrete



Note: All concrete streets meet the requirements of a 10-ton road/design.