International Comparison of Flexible Pavement Design (Sweden, Norway, Iceland, Denmark, Minnesota)

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ABSTRACT: The goal of this research is to investigate each agencies current design method to discover similarities and differences in the way each agency designs and builds roadways for both low and high volume roads. Each agency was given design specific inputs of common climate, traffic, and existing subgrade soil (from MnROAD) and was asked to develop a design based on current design practice/standards. This paper documented the differences in construction, materials, and expectations on performance to provide and will provide a bases for future agency discussion. The initial survey contained more information that could be covered in this paper. Future goals could include the additional information for other research topics, developing possible test sections, and again to provide a common point of discussion for future efforts. This work also builds off of the efforts started with the NVF34/Nord FOU concept at the 2007 Iceland workshop.

KEY WORDS: Mechanistic Pavement Flexible Design, Hot Mix Asphalt, Low Volume Road

1 INTRODUCTION

Minnesota and Sweden initially developed the idea for this paper and proposed each group were given design inputs based on a common climate, traffic, and existing soil (from MnROAD) and be asked to develop a design based on their current practice for both a low volume and high volume roadway. Detailed inputs were provided and the agencies will use everything or only what they need for their designs. Thirty survey questions were asked and are available upon request, but only a few of the questions are included in this paper.

2 DESIGN INPUTS

Minnesota provided climate, traffic, and native soil information from MnROAD (Albertville, Minnesota) to provide design inputs for the agencies to use. The information provided was very detailed but each agency could determine how much they needed for their design calculation.

Climate data was summarized from a weather station located at the Buffalo, Minnesota airport and provided to the designers. This location has long winters with frost depths reaching 7 ft with max low air temperatures of -40C (-40F) and 39C (102F) for highs air temperatures in the summer. Climate data was from Weather Underground website.

The native soil is classified as a silty clay. It has a high water table 1.5M (5 ft) and during the winters has a 1.5M (5 ft) of frost penetration. The R-value=12, coef var%=40, φ=.45, bulk specific gravity=2.7, dry bulk density = 1920 kg/m^3, seasonal modulus and duration of each season consists of 13 week fall at70 MPa, 17 week winter at 350 MPa, 8 week spring at 50 MPa, and 14 week summers at 60 MPa.

Traffic for the low volume design was designed at 15,000 ESALS/year (number of repetitions of 18,000 lb (80 kN) single axle loads applied on two sets of dual tires), No Growth factor, 20 yr design life (300,000 20-yr ESALS), load spectra MnROAD 5-axle semi, 80 laps/day (more information if needed), 2-Lane typical county road (3.65 meter/each lane) with traffic flow in opposite direction, 65 km/hr (40 MPH) design speed. Traffic for the interstate high volume roadway consists of 1,000,000 ESALS/year (number of repetitions of 18,000 lb (80 kN) single axle loads applied on two sets of dual tires), 3% growth factor, 20yr design life (36,122,224 20-yr ESALS), load spectra 35,000 vehicles/day with 14% trucks, legal load is 80,000 lbs (36,365 kg) total weight, 2-lane interstate road (3.65 meter/each lane) with traffic flow in the same direction, 110 km/hr (70 MPH) design speed, 100 kN ESAL's was used in European designs using the number of vehicles.

3 AGENCY STRUCTURAL DESIGNS

Each agency then designed both their high and low volume roadway for this paper using the common design inputs. A set of 30 questions were initially asked to help better understand their design methodology and served for the basis for this paper and to better understand each agency design. These responses are included in the responses from each agency and the similarities and differences will be reviewed. The shaded layers are the asphalt bound materials shown in each of the agency tables showing their designs for both high volume and low volume roadways.

3.1 Sweden Designs

Sweden uses a ME based design program called PMS Objekt ver. 5.0. It gives good results, robust method, easy to use, used by most of the industry. The negatives noted the design only accounts for fatigue in bitumen bound layers and no direct method for calculating permanent deformation in the pavement. The fatigue evaluation is only distress taken into account for the bitumen bound road-base layers. Figure 1 contains the designs from Sweden.

Sweden Low Volume Road

Shoulder	Driving Lanes	Shoulder
125mm **Unbound Road Base**	45mm **ABT16 HMA**	125mm **Unbound Road Base**
	80 mm **Unbound Road Base**	
420 mm **Unbound Subbase**		
610mm Embankment (mixed and recompacted native soil)		
Clay Subgrade (native soil – uncompacted)		

Sweden High Volume Road

Shoulder	Driving Lanes	Shoulder
35mm **ABS11 HMA**		
60mm **ABb16** AC Bind		
125mm **Unbound Road Base**	125mm **AG22** Bound Road Base	125mm **Unbound Road Base**
80 mm **Unbound Road Base**		
420 mm **Unbound Subbase**		
450 mm **GrSa** Protective layer		
610mm Embankment (mixed and recompacted native soil)		
Clay Subgrade (native soil – uncompacted)		

Or with Rock Base Design

Shoulder	Driving Lanes	Shoulder
35mm **ABS11** HMA		
60mm **ABb16** AC Bind		
125mm **Unbound Road Base**	125mm **AG22** Bound Road Base	125mm **Unbound Road Base**
80 mm **Unbound Road Base**		
200 mm **Unbound Subbase**		
800 mm Rockfill 0/180		
Clay Subgrade (native soil – uncompacted)		

Figure1: Sweden low and high volume structural designs.

3.2 Norway Designs

Norway uses a Norwegian pavement design handbook 018 to design their roadways. The positive for this design is it's easy to use. Its negatives include its purely empirical, table based method, difficult to use with new materials, and axle load calculations are based on out dated information (not updated for current traffic loading).

The Norwegian design procedure requires shoulders for all new roads to be paved, the same material as in the pavement. Blasted rock is a material produced as a result of blasting in the right-of-way during construction. It usually undergoes minimal further processing (sorting). The Norwegian pavement design manual does not require frost protection layer for such low volume roads but given that the frost penetration depth is 1.5m, a protection layer is considered necessary for the low volume road and added. Figure 2 has the Norwegian designs.

Norway Low Volume Road

Shoulder	Driving Lanes	Shoulder
	40mm **Agb11** HMA Surfacing	
50mm **Ag16**, B 160/220	50mm **Ag16** bitumen stabilized gravel base B160/220	50mm **Ag16**, B 160/220
	100mm **Fk 0/32** **crushed rock base**	
	500mm **22/120** **blasted rock subbase, sorted**	
	510mm **blasted rock frost protection layer** (same material as in subbase layer)	
	Geotextile fabric class 3	
	Subgrade (native soil – uncompacted)	

not to scale

Norway High Volume Road

Shoulder	Driving Lanes	Shoulder
	45mm **Ska16** SMA Surfacing B 70/100	
	35mm **Ab11** HMA Binder B 70/100	
	150mm **Ag 22** Stabilized Aggregate B 100/150	
	100mm **Fk 2/32** **Crushed rock** leveling course	
	800mm **sorted blasted rock subbase** Max. Size 75cm	
	670mm **sorted blasted rock** **frost protection layer** (same material as in subbase layer)	
	Geotextile fabric class 4	
	Subgrade (native soil – uncompacted)	

Figure2: Norway low and high volume structural designs.

3.3 Minnesota Designs

Minnesota Department of Transportation (MnDOT) is designing its flexible pavements using a mechanistic empirical based design MnPAVE 6.0. MnDOT used 50% reliability for low volume and 90% for high volume roads. MnPAVE's positives include its flexibility allowing three design levels depending on what information is known. It allows for a number of different materials, climate, and it allows detailed input of material testing, improvement from the past R-value designs. Negatives include assuming only subgrade rutting (no asphalt or base rutting) and MnPAVE allows for so many variations in design it can be a source of inconsistency between novice designers. See Figure3 for the MnDOT design.

Minnesota Low Volume Road

Shoulder	Driving Lanes	Shoulder
100mm **Class-2** Aggregate	100mm **SPWEB340C** HMA Superpave wear coarse PG 58-34 – traffic L3 ~25% RAP	100mm **Class-2** Aggregate
	200 mm **Class-5** Gravel Base	
	300mm Embankment (Reworked Subgrade) (native soil – uncompacted)	
	Clay Subgrade (native soil – uncompacted)	

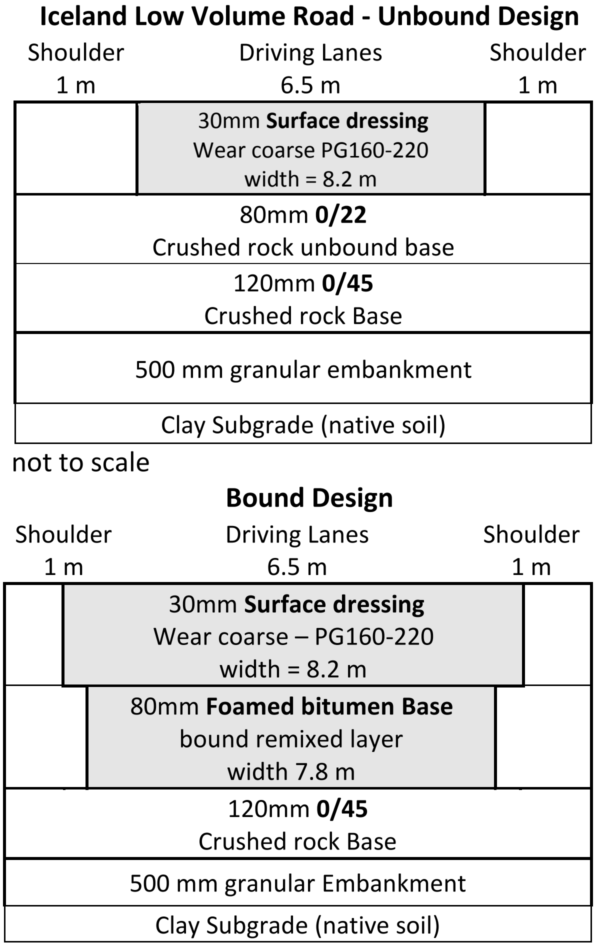
Minnesota High Volume Road

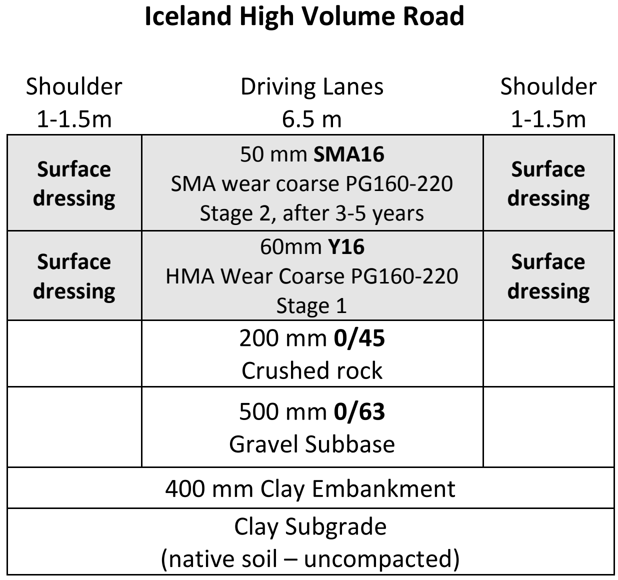
Shoulder	Driving Lanes	Shoulder
100mm **SPWEB3A** HMA Superpave Wear PG 52-34	100mm **SPWEB540F** HMA Superpave wear coarse PG 64-34 – traffic L5	100mm **SPWEB3A** HMA Superpave Wear PG 52-34
150mm **Class-5** Gravel Base	150mm **SPNWB530B** HMA Superpave Nonwear coarse PG 58-28 – traffic L5	150mm **Class-5** Gravel Base
	450 mm **Class-5** Gravel Base	
	900 mm **Class-3** Select Granular Sub-Base	
	300mm Embankment - (Reworked Subgrade) (native soil – uncompacted)	
	Clay Subgrade (native soil – uncompacted)	

Figure3: Minnesota low and high volume structural designs.

3.4 Iceland Designs

Iceland uses an experimental design called (ICERA) based on the Norwegian hb-018, which is fairly general and simple to use but lacks information on properties of materials parameters. Iceland's high volume roads are built in stages so that the second layer of AC is not expected until 3–5 years after the road is opened for traffic, but could though even be sooner, dependent on wear. Iceland typically does not have clay as subgrade but might find silty soil. The embankment thickness on top of silty soil would be minimum 500mm for low volume roads but might be increased up to 700 mm or even 1 m, dependent on material properties of the native soil. High volume roads the minimum thickness would be 900mm with higher requirements for the top 500mm. The total thickness of embankment might be increased to 1.2 m dependent on the silty subgrade. In the subbase and embankment, max stone cannot be larger than 2/3 of the layer thickness.





Iceland's older low volume roads are normally with 20cm crushed gravel or rock base. Shoulder used to be 25cm wide with gravel surface. Now these roads have been rebuilt, shoulder are wider, 1.0m and the base are bound with bitumen or cement and eventually built of crushed rock. New roads are usually designed with 200mm thick base of crushed rock, built as one or two layers.

Figure4: Iceland low and high volume structural designs.

Layer	Material	D mm	d mm	Percent Passing by weight					Percent Crushing
				2D	1,4D	D	d	d/2	
1st Lift (bottom)	Class	16	11	100	100	90 to 99	0 to 10	0 to 2	G_c90/10
2nd Lift (top)	Class	11	8	100	100	91 to 99	1 to 10	1 to 2	G_c90/10

Figure5: Iceland low volume surface dressing criteria

3.5 Denmark Designs

The designs below are in accordance to Danish specifications. The maximum frost penetration is assumed to be 900mm (applies for the high volume roads and where the soil is the most susceptible to frost). Assuming frost penetration of 1.5 m, the thickness of the BL-layer would be increased in order that the total thickness of the construction would be 1.5 m. The rest of the construction would be the same as below. Denmark – MMOPP2011 ME Design Software, Positive: Very easy and quick design method. Flexible with the choices of materials that can be used. Negatives include a lack of flexibility in relation to number of layers to be implemented in the design.

Denmark there is normally defined just one modulus for the native soil - both when used in an embankment as well as in the case of constructing the pavement layers on top of an uncompacted native soil, as shown in Figure 6 designs. The assumed E-modulus for the native soil is 30 MPa, both for the high volume road and for the low volume road (as the proposed design value for uncompacted native soil).

Denmark Low Volume Road

Shoulder	Driving Lanes	Shoulder
125mm **SG II** Unbound Granular	35 mm **AB** HMA 160/220	125mm **SG II** Unbound Granular
	90 mm **GABI** HMA 70/110	
150mm **SG II** Unbound Granular Base		
425 mm **BL II (0/63)** (*) Granular material		
Clay Subgrade E-modulus = 30 MPa (native soil – uncompacted)		

(*) BL II 0/63 gradation specification: No grains > 90mm; No more than 15% > 63mm; No more than 5 % > 0,063 mm.

Calculation of the input parameter for the equivalent 10-ton axle-load is according to the standard Danish procedures. Traffic load: 0.65 Mio 20-yr Equivalent 10-ton axles (Input in MMOPP2011 = 8250 pr. year)

Denmark High Volume Road

Shoulder	Driving Lanes	Shoulder
25 mm **SRS 8** SMA Modified		
70 mm **ABB Type II** HMA Modified		
80 mm **GABII** HMA 40/60	160 mm **GABII** HMA 40/60	80 mm **GABII** HMA 40/60
250 mm **SG II (0/31.5)** Granular Base	250 mm **SG II (0/31.5)** Granular Base	250 mm **SG II (0/31.5)** Granular Base
570 mm **BL II (0/63)** Granular Material	490 mm **BL II (0/63)** Granular Material	570 mm **BL II (0/63)** Granular Material
Clay Subgrade E-modulus = 30 MPa (native soil – uncompacted)		

(*) BL II 0/63 gradation specification: No grains > 90mm; No more than 15% > 63mm; No more than 5 % > 0,063 mm.

Calculation of the input parameter for the equivalent 10-ton axle-load is according to the standard Danish procedures. The calculations are based on 4900 trucks/day (14 % of the total 35.000 vehicles) and a yearly growth factor of 3 %. The Danish definition of Truck is a vehicle with total weight of 3.5 tons and over.

Figure6: Denmark low and high volume structural designs.

4 DESIGN OBSERVATIONS

The following observations were made after reviewing each of the five designs related to design methods, layer thicknesses, surfaces, high volume wear and non-wear surfaces, low volume, base, subgrade.

4.1 Design Methods Observations

The following observations can be made between design methods.

- Sweden, Denmark, Minnesota have moved to an updated computerized ME design process and Norway and Iceland are using a design handbook which is based on an older empirical Norwegian design method.
- Current designs design for fatigue (2), bearing capacity including base/subgrade rutting (4), cracking (3), frost heave (2), potholes (2), ride (1), where the number represent the agencies responses.
- All five agencies noted that their current system is easy to use (positive) but then at the same time it's too easy to use (negative) where with a few click in a program can get you a design. This design can include a wide range of thicknesses and material layers which an inexperienced designer can overlook many important design aspects.
- More material knowledge is needed (response) and the models need to be updated for the ME based designs to better represent actual field performance.
- 3 of the 5 agencies use studded tires which they use high quality durable aggregates in their designs to help prevent wear (HMA rutting), which two agencies don't need to worry about studded tires.

4.2 Layer Thickness (Designs)

Some observations on the low volume road designs which also looks at the total bound layer and unbound layers in the tables below. This is over simplified because it groups higher quality layers with lower quality layers for example crushed rock bases with sandy bases.

- Wide range of surface and base thicknesses
- Two agencies use embankments of remixed clay – Minnesota it is optional

Layer / Agency	Sweden	Norway	Iceland Rock Design	Iceland Bound Base	Denmark	Minnesota
Asphalt Bound (mm)	45	90	30	80	125	100
Unbound Granular (mm)	500	1100	700	620	575	200
Embankment – clay (mm)	600	--	--	--	--	300
Clay subgrade						

Table 1 – Low volume road designs layers simplified

Layer / Agency	Sweden Non-rock	Sweden Rock	Norway	Iceland	Denmark	Minnesota
Asphalt Bound (mm)	220	220	230	110	255	250
Unbound Granular (mm)	950	1080	1570	700	740	1350
Embankment – clay (mm)	610	--	--	400	--	300
Clay subgrade						

Table 2 – High volume road designs layers simplified

4.3 Surface Observations

Figures 7-9 show the asphalt layer gradations. It is interesting to note that Minnesota uses nearly 100% drum plants and the other 4 agencies use nearly 100% batch plants in the production of its asphalt mixes. General observations include:

- 4 agencies use a stabilized bound road base for strength. Iceland notes that in the past they used 3-4% foamed asphalt but they are moving towards using more cement stabilization.

- 2 agencies (Denmark, Minnesota) use modified asphalt binders and 4 agencies use penetration graded asphalts and Minnesota uses a performance graded system (PG)
- Each agency uses a high crushing percent for their high volume mixes and less for their lower volume mixes.
- Minnesota uses primarily drum plants and the four other European agencies use batch plants. This might be significant difference related to performance when production outweighs quality of the asphalt mixing operations.

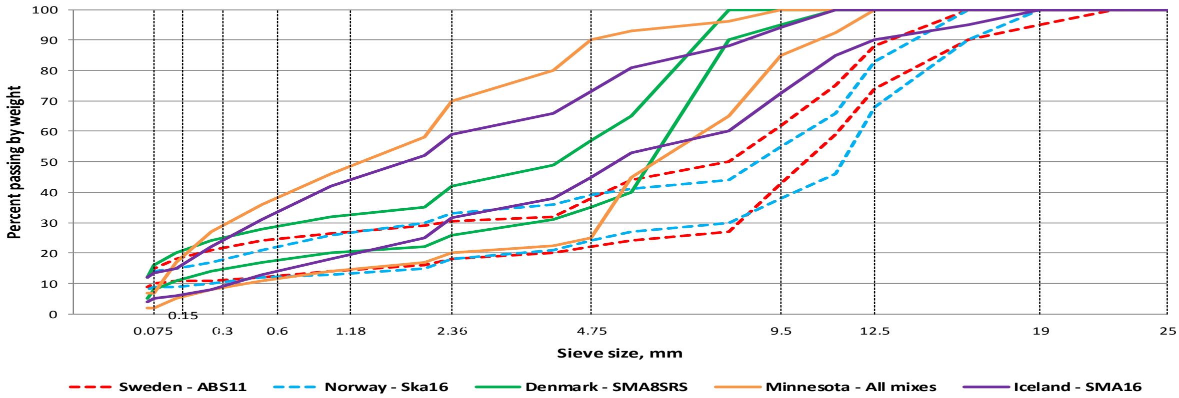


Figure7: Asphalt high volume wear coarse gradations

4.4 High volume wear surface observations

- Minnesota has the widest gradation bands and has a finer gradation for its high volume roads wear coarse.
- Demark, Iceland, Norway, Sweden have narrower gradation bands for their high volume road wearing coarse.
- 2 agencies use a SMA design for their high volume roads rest HMA designs.
- Norway and Sweden have the coarsest gradations for their high volume roadways wear coarse probably due to the use of studded tires in the winter.
- Iceland uses a two stage surfacing on their high volume roadways added in 3-5 years.

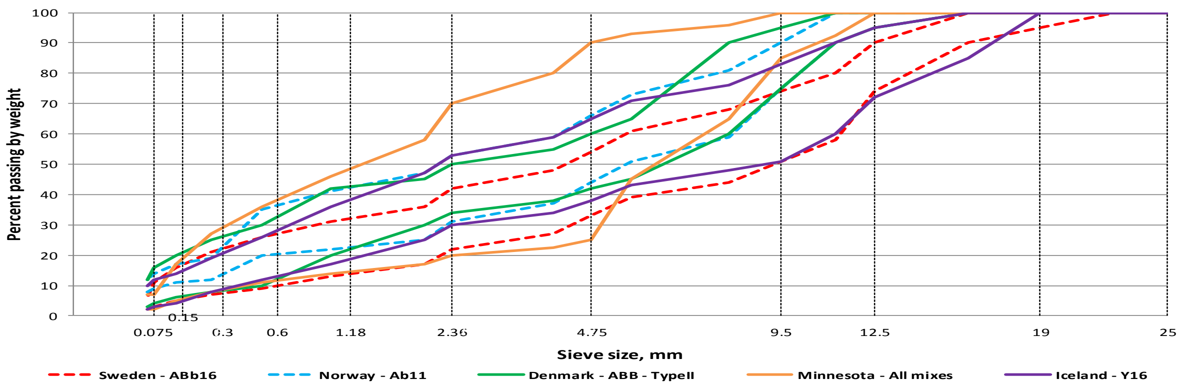


Figure8: Asphalt high volume nonwear gradations

4.5 High volume non-wear coarse observations

- Gradations for the high volume non-wear coarse are more similar to each other than Minnesota uses a finer wider gradation, which allows more variation.

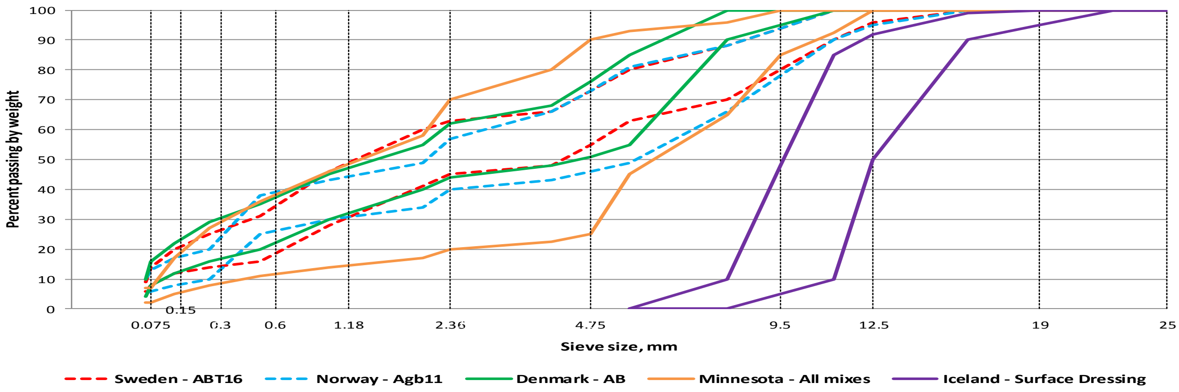


Figure9: Asphalt low volume wear gradations

4.6 Low volume surface observations

- Iceland uses a surface dressing as a driving surface for their low volume designs
- Minnesota has the widest gradation band for the low volume wear and the other agencies fit inside with narrower bands.
- Minnesota is the only one using ~25% recycled asphalt (RAP) for low volume designs.

4.7 Base Observations

- Sweden and Iceland have very narrow bands for their high volume base gradations (directly under the bound surface layer).
- Minnesota again has a wide band and its specs accept much finer base gradations than the rest for high volume base gradations. Top size for Minnesota might be 25mm where the others accept 50mm.
- Sweden has both a delivered and after construction gradation requirements. They also showed some average gradations. MnDOT has some issues with its limestone base materials changing (crushing) during construction activities but only uses a delivered gradation for payment.
- Sweden, Norway, Iceland use larger crushed rock for unbound base materials.
- MnDOT class-3 and class-5 gradation bands are more open (wider bands) than the other four countries. This could account for the wide range of base material properties when we spec out a class-5 unbound base. Future action to review the gradations MnDOT uses. How can MnPAVE predict the material properties?
- Edge drains are not a typical design feature used in any agency roadways, but are used in special situations.

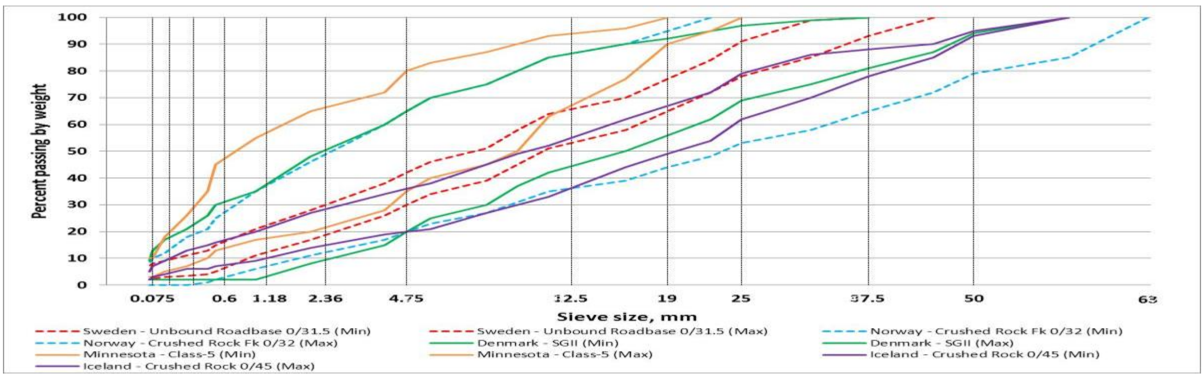


Figure10: High volume granular base gradations (directly under the bound layer)

4.8 Subgrade Observations

Two of the agencies rework the clay subgrade to form an embankment layer ranging from 300-600mm 610mm (Sweden but depends if you use a rockfill), 0-700 mm (Iceland – uses a granular embankment by definition), and Minnesota uses typically 300mm in the past but now that is subjective depending on the engineers judgment.

5 CONCLUSIONS

Though this process of designing a low volume road (300,000/20 years ESALS) and a high volume road (36 million/20 year ESALS) a number of observations can be made.

- Designing for a roadway on Interstate-94 (high volume) maybe unrealistic for most agencies including MnDOT since we don't have too many roadways with this amount of traffic. Maybe a 3 to 5 million/20 year ESAL deign would have been more realistic for each agency to use for this comparison.
- Each agency is still working to develop a simple and easy tool to develop their designs. Three of the five agencies use a mechanistic empirical design program but improvements still need to be made for the wide variety of materials used and updates are needed of the models predicting performance.
- The design systems are developed based on locally available materials. For example Norway relies heavily on crushed rock materials in road building compared to the other agencies.
- Layer structures "thickness" varies by agency.
- Gradations vary for both the asphalt layers and the bound surface layers. Minnesota has the widest gradation bands and the most fine for all materials.

REFERENCES

MnROAD Traffic and Subgrade Information - Minnesota Department of Transportation, *MnROAD Data Release 1.0*, http://www.dot.state.mn.us/mnroad/dataproduct/index.html, January 2012.

Climatic Data for Buffalo, Minnesota, USA provided by Weather Underground Website, http://www.wunderground.com/q/zmw:55313.1.99999

MnPAVE Design Software 6.202., Minnesota Department of Transportation Materials Web Site, http://www.dot.state.mn.us/app/mnpave/index.html

PMS Objekt Version 4.2 Design Software, Swedish Transport Administration web site http://www.trafikverket.se/Foretag/Bygga-och-underhalla/Vag/Tekniska-dokument/Vagteknik/PMS-Objekt/

Norway Design, Handbook 018 (in Norwegian), Norwegian Public Roads Administration, 2005.