Norwegian experiences and conclusions regarding Gyratory Compactors

R. Bragstad
Asfaltteknisk institutt, Oslo, Norway

R.Telle
Lemminkäinen Norge AS, Oslo, Norway

ABSTRACT: The Norwegian research project PROKAS was conducted in 1998-2004. One of the goals of the project has been to evaluate the suitability of the gyratory compactor for mix design of asphalt in stead of using the Marshall method. Another goal has been to establish a method for using the gyratory compactor for preparing specimens for further testing. The results are showing a variation between different gyratory compactors for the same asphalt mixture that is not satisfactory regarding the compaction curves. Although the gyratory angle is set according to the description from the manufacturer, there is a significant deviation of internal angles in the mould during compaction between different compactors (and also between the top and bottom plate in the same compactor). There are also results indicating that the compaction curves are very sensitive to small changes in the gradation curve of the stone material. By testing different mix compositions of the same asphalt mixtures that have performed well under traffic, recommendations have been made regarding how the compaction curves for an asphalt mixture should look like to perform well in the field. The Finnish compactors (ICT) used in Norway have the ability to measure the shear force applied to the specimen during compaction. The equipment used for measuring the internal angle have proven to be useful also for adjusting the levels of shear curves from different Gyratory compactors for comparing purposes. Based on an investigation for voids distribution in the different parts of the specimens a method for preparing specimens for further testing has been chosen. This has been done despite of the fact that tests on specimen taken from the road show different levels of results.

KEY WORDS: Asphalt mixture, mix design, gyratory compactor

1 BACKGROUND

The main objectives of the investigation of gyratory compactors in the PROKAS project are to produce laboratory specimens which have the same internal structure distribution as specimens that are compacted in the field, and use the specimens 1) to carry out volumetric mix design and 2) testing the mechanical properties of the mixture.

Lemminkäinen, NCC, Nynäs, Sintef, The Norwegian Road Authorities and Kolo Veidekke have participated in the laboratory work. Four of the laboratories (B, D, E and F) use the gyratory compactor ICT-150 RB, one laboratory (A) uses ICT-150 RB model III and one laboratory (C) uses Cooper Gyrocomp.

The following adjustments were used; the applied pressure 600 kPa and the angle of gyration 1,0°.

The work consists of several activities:

- Two round robin tests to investigate variations of results between different laboratories and compactors and to look into how to calibrate the equipments.
- Compare variations of void content between Marshall specimens and Gyratory specimens.
- Investigation of density distribution in gyrator specimens for the purpose of using the specimens for testing of mechanical properties of the mixture.
- Mix design of Stone mastic asphalt (Ska 16) with four different binder contents. The purpose is to investigate if an optimum binder content can be determined for a given gradation curve of stone material.
- Compaction of laboratory mixes of three different asphalt mixtures (Agb, Ab and Ska) that have shown good results in the field. The results are used to predict a satisfactory compaction curve for each mix type.
- Testing of equipment (ILS – Invelop Load Simulator) for measuring the angle of gyration under compaction.

The asphalt mixtures that are referred to in this paper are Agb and Ab, which both are types of asphalt concrete, Agb for low traffic roads and Ab for roads with medium high traffic, and Ska, which is stone mastic asphalt for high traffic roads. Figure 1 shows typical gradations curves for these three asphalt mixtures.

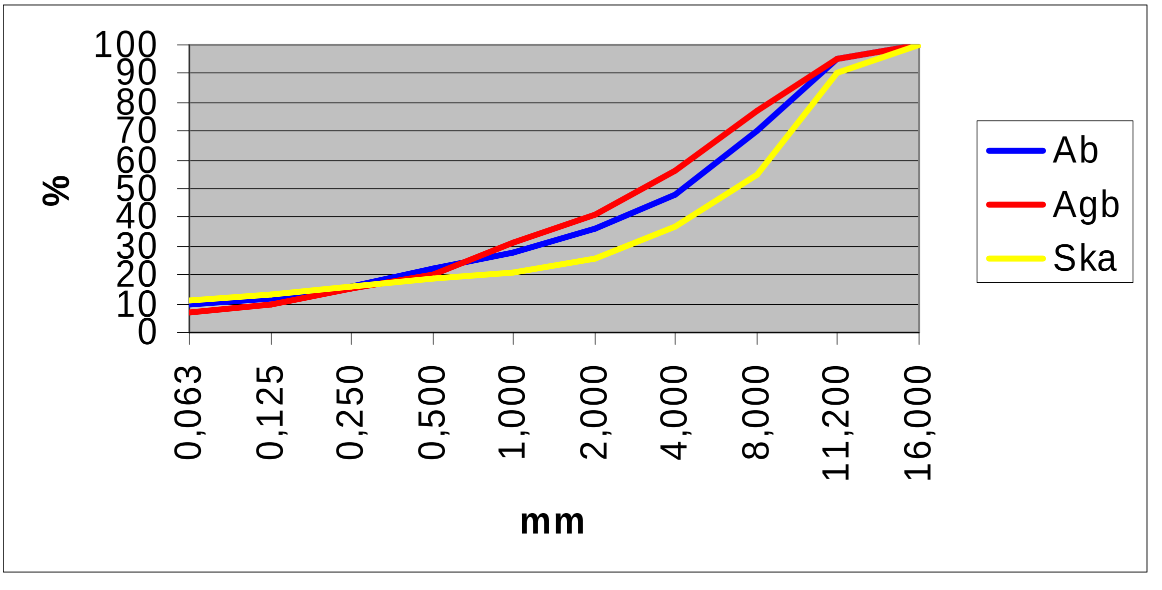

Figure 1: Curves for three Norwegian asphalt mixtures used in the gyrator project.

2 RESULTS

2.1 Comparison of gyratory compactors

In the first round robin test all participants compacted the same mixture (Agb 11) mixed both in their oun laboratory (100 mm mould) and at an asphalt plant (100 and 150 mm mould). The gyratory angle was set at $1,0^{O}$ in accordance with the manual. Figure 2 shows that the variations between the laboratories are so large that it is not possible to make a specification which specifies to choose a binder content that gives a certain void content after a given number of gyrations. There are also big variations between the specimens from each laboratory.

In order to reduce the difference between gyratory compactors a second round robin test was carried out. In this case the gyratory angle was adjusted to give a reference mixture a given density at 80 revolutions in the compactor. After the adjustment a mixture (Agb 11) from an asphalt plant was compacted. Figure 3 shows the results. As shown in Table 1 the standard deviation is almost the same as in the first round robin test for 100 mm mould, but improved a little for 150 mm mould. Mainly because laboratory A here is more in level with the other laboratories. The reason could be that laboratory A has stiffer equipment (ICT-150 RB model III). Compaction with a 150 mm mould is heavier than with a 100 mm moulds and the gyratory could therefore twist in a way that affects the angle.

Table 1: Standard deviation between the laboratories

	Mould diameter (mm)	Standard deviation of void content between the laboratories	
		Hydrostatic	Gyratory
Round robin test 1	100	0,62	0,70
	150	1,25	1,09
Round robin test 2	100	0,64	0,47
	150	0,58	0,44

Table 2 shows that the mean standard deviation for the parallels within each laboratory has increased from round robin test 1 to 2.

Table 2: Average standard deviation within the laboratories

	Mould diameter (mm)	Average standard deviation of hydrostatic density, within the laboratories
Round robin test 1	100	0,005
	150	0,009
Round robin test 2	100	0,011
	150	0,015

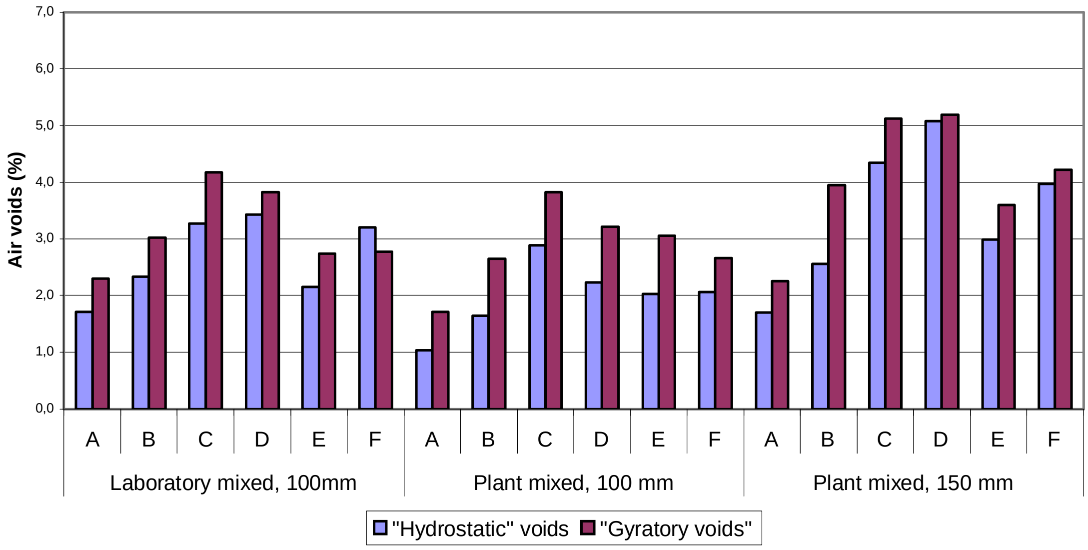

Figure 2: Round robin test 1, void contents for the laboratories A to F

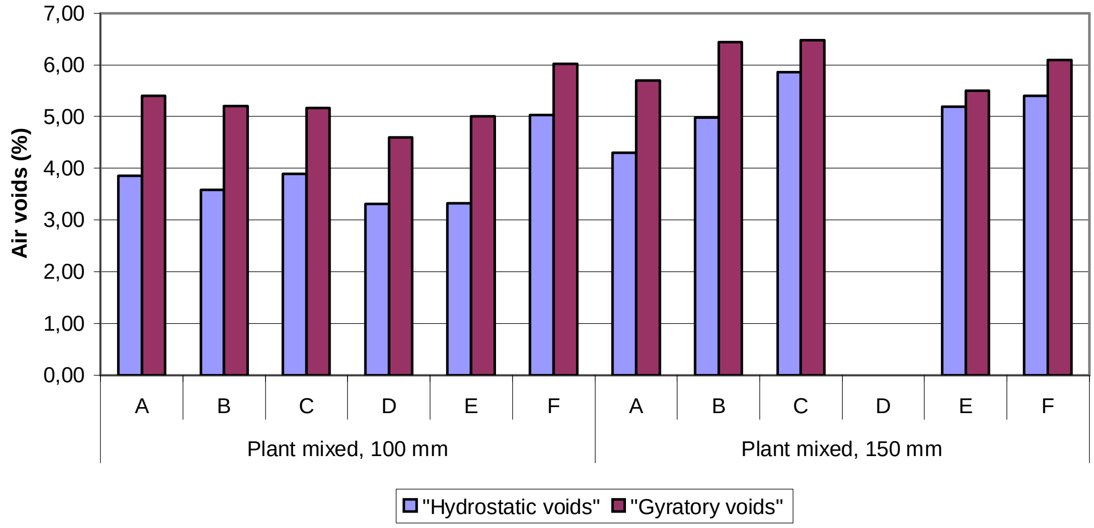

Figure 3: Round robin test 2, void contents for the laboratories A to F

Marshall specimens and gyratory specimens, 100 mm mould, were compared for hydrostatic surface dry density, void content and indirect tensile strength. The gyratory specimens were compacted with 200 revolutions, height 100 mm, and then cut from both ends to the same hight as the Marshall specimens, 65mm. Table 3 shows the results.

Table 3: Results of comparison between specimens compacted with Marshall and Gyratory compaction

	Hydrostatic density”		Void content (%)	Structural coefficient	
	Standard deviation between laboratories	Average standard deviation within a laboratory	Average all laboratories	Average all laboratories	Standard deviation between laboratories
Gyratory	0,017	0,012	2,6	3,46	0,10
Marshall	0,010	0,007	3,3	3,50	0,07

2.2 Study number three: Internal structure distribution

It has been documented in other works that the void distribution shows variation within gyratory specimens. Therefore, it was decided that the void distribution of the specimens is examined. Emphasis was placed on equal preparing of the mixture in the different laboratories before gyration to obtain the same temperature in the mix. Three laboratories made ten specimens each with diameter 150 mm and height approx. 110 mm. A core with 100 mm diameter was drilled out of the 150 mm specimens. For half of all specimens the core and the outer rings were split into three parts; upper, middle and bottom. These pieces were used to investigate the density distribution. For the other half of the specimens new specimens were produced of the middle part of the core with height of 60 mm. These specimens were used for testing of E-modulus and indirect tensile strength.

Figure 4 shows the void distribution within the gyratory specimens. In this case the angle was again set to $1{,}0^{O}$. Laboratory A (ICT-150 RB model III) has the highest density in specimens and laboratory C (Cooper Gyrocomp) has the lowest density in specimens. This is in accordance with the results in the first round robin test. All the cores have the highest density in the middle and have one to three percent higher void content at the top and bottom, depending on the gyratory compactor. The “shell” shows greater variations. The samples from laboratory A show equal distribution from top to bottom, laboratory E shows increasing voids downwards and laboratory C shows increasing voids upwards in the shell.

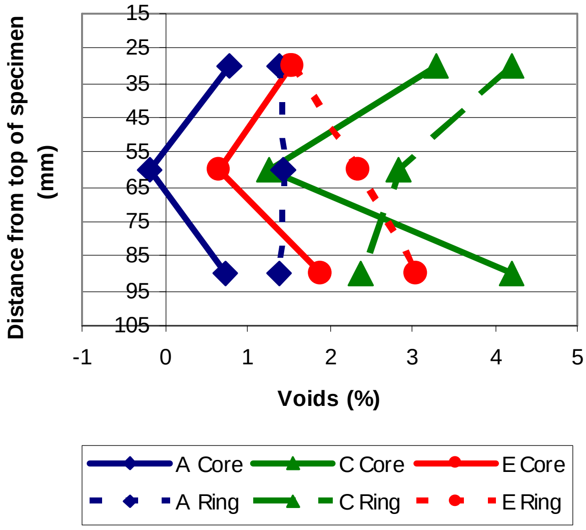

Figure 4: Distribution of air voids in specimen compacted with gyratory compactor

As shown in Table 4 the E-modulus tested with Nottingham Asphalt Tester (NAT) and the indirect tensile test show no significant difference in results between the laboratories. The results did not correlate with the void content in the specimens.

Table 4: Results from testing of E-modulus and the indirect tensile test

Laboratory	Void content	E-modulus (MPa)	Indirect tensile strength (kPa)
E	0,1 – 1,1	1020	960
C	1,5 – 1,8	917	965
A	0 – 1,1	870	934

2.3 Study number four: Volumetric mix design of Ska 16

The aim of the fourth study was to see if a mixture with four different binder contents, 0,5 % increment of binder content for each new mix, give significant differences in the compaction curves. The forth study was divided in four substudies:

Substudy number 4-1: Ska 16 was mixed in the laboratory with the same gradation curves and four different binder contents. Four mix portions were made for each of the participating laboratories. Binder and fines were sticking to the mixer especially for the mixes with the highest binder content. This separation led to an uncertainty regarding the binder content of the different mixes. The average compaction curve for each binder content for all the laboratories showed the effect of different binder contents, but the results for each laboratory were not that clear.

Substudy number 4-2: In this case laboratory E used its own laboratory mixer to mix portions for one laboratory with the same gradation and bitumen contents as in substudy number 4-1. All the specimens were compacted with the gyratory compactor of laboratory E. This new laboratory mixer was expected not to separate the mixture as the first one did, but still the results were varying as they did earlier.

Substudy number 4-3: This time laboratory E sieved the stone materials, and weighted in the exact amount on every sieve for four test portions. Every portion was individually mixed with 6,0 % biinder. This gave compaction curves that were much more coincident than for the two earlier substudies.

2.4 Study number 5: Compaction curves for different mix types

Each of the participating asphalt producers, who had their own gyratory compactor, mixed in their laboratories test specimens of three different hot mix asphalt types: Ska 11 (SMA), Ab 11 (AC) and Agb 11 (AC). The mix formulations chosen were ones found to behave well on the road. The compaction curves found this way spanned an area characteristic for the different mix types, see Figure 5. Figure 6 shows typical shear force curves for the same mixes. The stippled curves are the slope of the compaction curves expressed as the difference in void content after n gyrations and the void content found thereafter divided by the number of gyrations between the two measurements of void content. The slope is scaled to the same magnitude as the shear force curves and shows some similarity in shape.

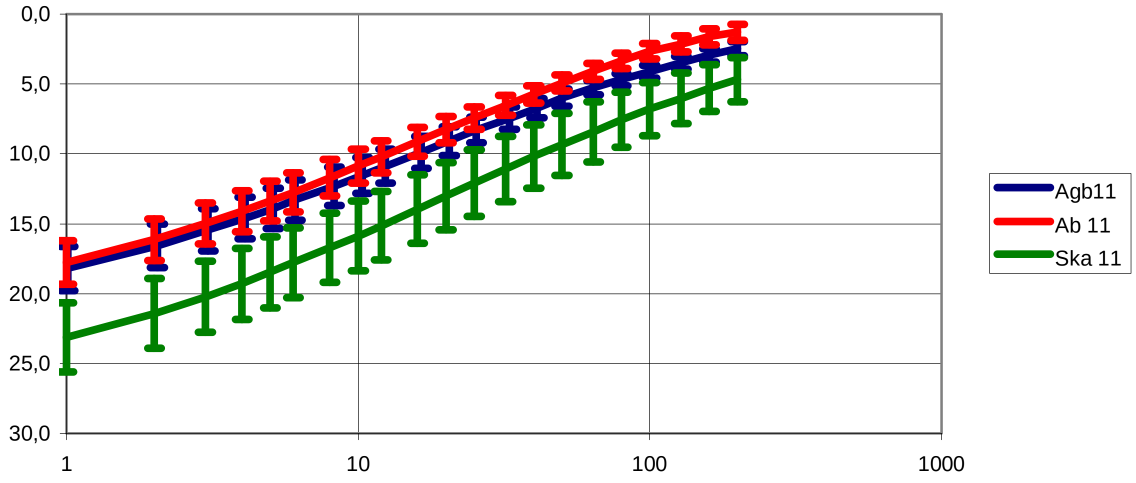

Figure 5: Typical compaction curves for Agb, Ab and Ska 11 with areas of variation

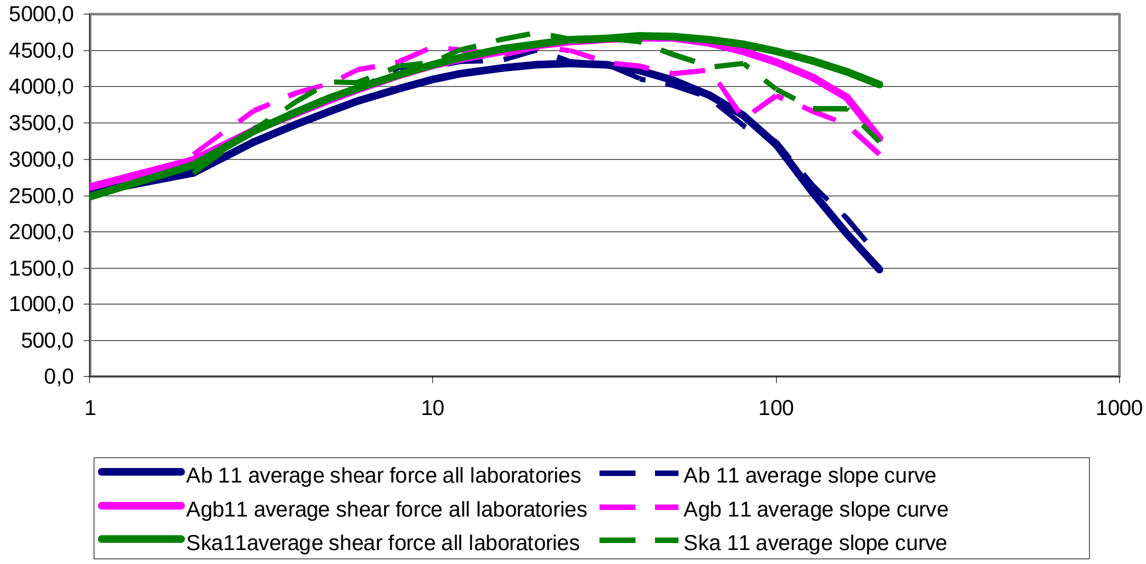

Figure 6: Shear force and the slope of the compaction curve

The shear forces seem for all the mix types to reach a maximum, but after a different number of gyrations. Ab 11 tends at the end to fall below the initial shear force, while the Ska 11 does not tend to fall much after the maximum.

Table 5 shows the results from laboratories A, B and F after measuring the void content and voids filled with bitumen. These are based on density of the specimens that was measured by the gyratory compactor during compaction: Laboratories B and F also determined the density by the hydrostatic surface dry method after 200 gyrations. Laboratory B made additionally Marshall specimens of the same mixtures (2x75 blows).

Table 5: Void content and voids filled with bitumen after 10, 80, and 200 gyrations

Mix type/ Laboratory	Void cont. (%) Gyratory comp. 10	80	200	Void content (%) Hydrostatic surface dry 80[1)]	200	Mar-shall	Voids filled with bitumen 80 Gyr	80 hyd[1)]	200 Gyr	200 Hyd	Mar-shall
Agb 11/A	10,3	4,2	1,9								
Agb 11/B	12,6	4,6	1,8	4,4	1,5	2,9	74,5	75,7	88,6	90,3	82,2
Agb 11/F	11,1	5,1	3,0	5,0	2,9		72,3	72,5	81,9	82,3	
Average Agb 11	**11,3**	**4,6**	**2,2**	**4,7**	**2,2**	**2,9**	**73,4**	**74,1**	**85,3**	**86,3**	**82,2**
Ab 11/A	10,6	3,1	1,8	1,5	0,2		81,6	90,2	88,6	98,4	
Ab 11/B	12,5	3,7	0,9	2,6	0,4	2,6	78,6	84,3	93,9	97,3	84,0
Ab 11/F	9,3	3,3	1,6	3,1	1,4		80,4	81,6	89,6	91,1	
Average Ab 11	**10,8**	**3,4**	**1,4**	**2,4**	**0,7**	**2,6**	**80,2**	**85,40**	**90,7**	**95,6**	**84,0**
Ska 11/A	13,3	5,6	3,1								
Ska 11/B	18,8	10,0	6,9	7,4	4	6,6	57,0	65,0	66,6	78,0	67,2
Ska 11/F	15,5	8,2	5,5	6,5	3,8		62,4	68,0	71,8	79,1	
Average Ska 11	**15,9**	**7,9**	**5,2**	**6,9**	**3,9**	**6,6**	**59,7**	**66,5**	**69,2**	**78,5**	**67,2**

1) The hydrostatic void content after 80 gyrations is determined by adjusting the void content, which is based on the density measured during compaction with the ratio between the hydrostatic void content and the one based on measurements after 200 gyrations.

The results indicates that the void content and voids filled with bitumen of the Marshall specimens are of the same magnitude as the void content measured by "hydrostatic surface dry density" after 80 gyrations.

3 ANGLE MEASUREMENTS

An equipment for measuring the internal angle between a line perpendicular to the top (or bottom) plate and the inside wall of the mould, was tested during the fifth study. The equipment is made by Invelop Oy, the same company that has made the compactors. By placing smaller or bigger rings at the top and bottom of the equipment it is possible to simulate smaller or bigger resistance against being tilted to the set angle of the gyratory compactor. Figure 7 shows how a bigger ring will make it harder to tilt the top and bottom plate than a small one. For that reason the equipment is called ILS (Invelop Load Simulator).

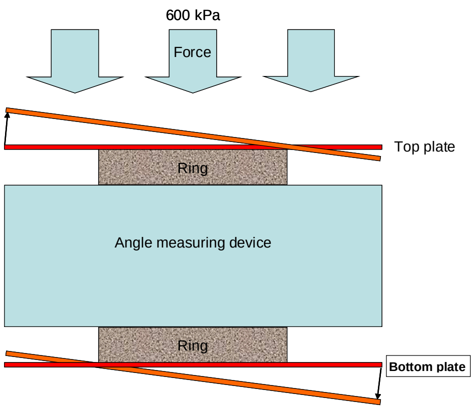

Figure 7: Measuring device for internal gyratory angel

Table 6 shows the results from the angle measurements. The gyratory angle was in advance set to 1,0° according to the specifications from the manufacturer of the gyratory compactor.

Table 6: Angle measurements results

		Small rings			**Big rings**		
		Parallel A	Parallel B	Average	Parallel A	Parallel B	Average
B	Top	0,943°	0,926°	0,935°	0,591°	0,637°	0,614°
	Bottom	0,778°	0,773°	0,776°	0,181°	0,209°	0,195°
A	Top	0,930°	0,920°	0,925°	0,797°	0,802°	0,800°
	Bottom	0,919°	0,920°	0,920°	0,532°	0,371°	0,452°
F	Top	0,846°	0,865°	0,855°	0,681°	0,669°	0,675°
	Bottom	0,354°	0,375°	0,365°	0,203°	0,213°	0,208°
E	Top	0,921°	0,936°	0,929°	0,738°	0,750°	0,744°
	Bottom	0,693°	0,616°	0,655°	0,257°	0,240°	0,249°

As seen from Table 6 laboratory A has the least difference between the angle measured between the inside wall of the mould and a line perpendicular to respectively the top and the bottom plate. This is presumable because their gyratory compactor is of a newer and stiffer model that keeps the endplates more parallel.

During the angle measurements the compactors measured the distance between the endplates and the shear force as usual. Since the two sets of rings used during angle measurements represent two fixed levels of shear force, it is possible to find shift factors that can bring measurements with different compactors to the same level. Adjusted shear force values measured during the angle measurements are shown in Figure 8 together with the adjusted average of the four highest shear force measurements made during the compaction of each of the mixes in study number five.

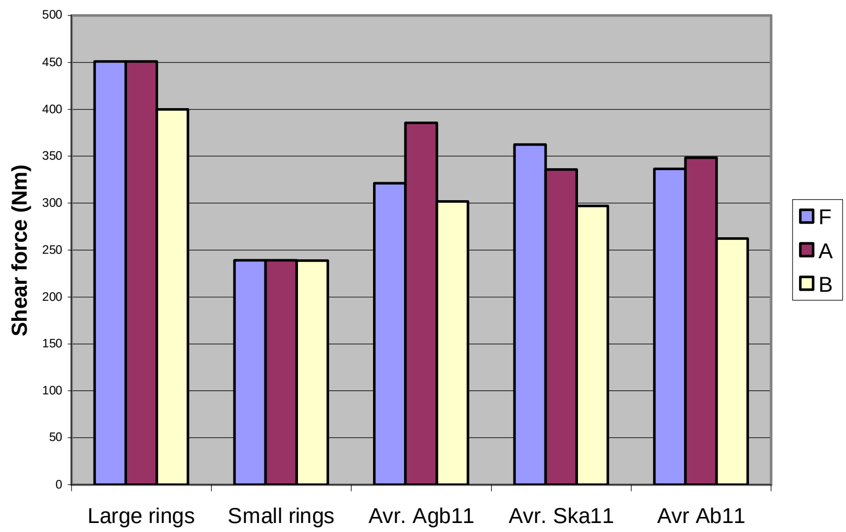

Figure 8: Shear forces measured during measuring of gyratory angle and compaction of mixes adjusted to the same level

The angle measurements made on the compactor of laboratory B were done with smaller big rings than those used for the laboratories A and F. Figure 8 shows that the maximum shear forces of the asphalt mixes falls between the ones measured during the angle measurements.

4 CONCLUSIONS

These conclusions are based on few experiments and should therefore be used with caution.

- The results from round robin test 1 and 2 and substudy 4 show that the compaction curves for the same asphalt mix compacted with different gyratory compactors in different laboratories have variations between the laboratories that makes it difficult to specify that a mix should have a certain binder content that gives a certain void content after a given number of gyrations. Even parallels within one laboratory vary so much that it may be difficult to find the effect of the chosen binder contents. Specimens made by Marshall compaction show less variation.
- The variation between the laboratories decreases when calibrating the gyratory angle by choosing the one for each gyratory compactor that gave the same density after 80 gyrations for a reference mix,. But still the variation between parallels within each laboratory was the same. One reason for this variation might be that the compaction method is very sensible to even small separations. The laboratory practice when mixing the asphalt has been to weigh in stone fractions, mix with the wanted binder content, and then split the mix down to the desired specimen size. One single test where the stone material was weighed separately on every sieve, and mixed one test portion at the time, showed less variation.
- The ILS equipment for measuring the gyratory angle inside the mould might be an alternative way of setting the gyratory angle to the same value at the same load level for different gyratory compactors. This will be easier than using reference mixes which shall achieve a certain density after a given number of gyrations.
- The ILS equipment might also be used to find scale factors which make it possible to compare the shear force curves from different compactors.
- Based on the fifth study it has been proposed intervals that compaction curves for Agb 11, Ab 11 and Ska 11 normally should be within. It has not been possible to suggest methods to find an optimum binder content on the basis of the compaction curves.
- Estimated values for density found by hydrostatic saturated surface dry method might be used to calculate the void content and voids filled with bitumen after 80 gyrations. The density after 80 gyrations is found by adjusting the density found by measurement during compaction with the ratio between the density found after 200 gyrations by the hydrostatic saturated surface dry method and the density based on measurements. The calculated void content and voids filled with bitumen might be evaluated with the same values used in the Marshall specifications after 2x75 blows.
- The shape of the shear force curve seems to be characteristic for the different mix types.
- A plot of the change in the slope angle of the compaction curve has a shape similar to the shear force curve.
- After 200 gyrations are the specimens denser than Marshall specimens compacted with 2X75 blows, and they are not suited for further testing. If for instance specimens with diameter 150 mm and height 60 mm are to be made for cyclic creep testing, then should first 100 mm high specimens be made and then should 20 mm be sawed off the top and bottom. The number of gyrations should be chosen so that the sawed specimen has a void content similar to what found in cores taken from the road for that mix type. The needed number of gyrations should not be too low or high, normally between 30 and 80.