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Aggregate investigations in the Gulestø area in Bremanger

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

Geological Survey of Norway
N-7441 Trondheim, Norway
Tel.: 47 73 90 40 11
Telefax 47 73 92 16 20

REPORT

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Title:
Aggregate investigations in the Gulestø area in Bremanger

Authors: Arnhild Ulvik and Peer-Richard Neeb		Client: NOR Engineering AS/Bremanger Aggregates AS	
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Summary:

As a commissioned project for NOR Engineering AS / Bremanger Aggregates AS NGU has made an examination of Devonian sandstones in an area to the west of Gulestø in Bremanger municipality. NGU has collected and analysed two samples from this area.

The area appears to be interesting on the basis of earlier analytical results in the neighbourhood, and because the natural conditions are appropriate for establishing a large coastal aggregate quarry. Large-scale extraction of aggregates requires sufficiently large volumes of reserves. A proposal for an extraction plan employs a volume of approximately 165 million tonnes. The reserves, however, are much larger, and the possibility for an extension of the reserves demonstrated is good.

Because requirements vary with regard to both the area of use and the European country concerned, it is difficult to give an overall appraisal of the quality of the rock type at Gulestø. In general, the quality is considered as very good. The analysed samples show particularly good PSV and Los Angeles values, fulfilling virtually the strictest demands placed on road surfaces with high traffic loads. The appraisal has been made in relation to the quality requirements for building raw materials in England, Germany, France, the Netherlands and Norway.

Keywords: Engineering geology	Building raw materials	Microscopy
Norwegian Impact Test	Abrasion	Ball mill
Los Angeles Test	Polished stone value	Scientific report

CONTENTS

APPENDIX

1. PREFACE

NGU has earlier evaluated potentially suitable deposits for aggregate production in the Bremanger area. Based on bedrock geology maps, previous aggregate investigations in the area, topographical maps, municipal plans, conditions for building quays and meetings with the council, three areas on Bremangerland were initially considered suitable.

Areas in the southwestern part of Bremanger, where sandstone outcrops, were also investigated as far as the boundary to Flora, south of Frøysjø. The areas were examined and sampled in 1996.

In July 1999 a further two sandstone samples were collected for analysis at Gulestø. The results of this testing are discussed in this report.

Trondheim, 20th of September 1999
Project Group for Building Raw Materials

Peer-Richard Neeb
Peer-Richard Neeb
Project Manager

Arnhild Ulvik
Arnhild Ulvik
Senior Engineer

2. INTRODUCTION

Three years ago NGU located areas where natural conditions are appropriate for establishing major coastal facilities for aggregate production in Bremanger municipality. The work must be viewed against the background of previous aggregate investigations in the area. The coastal area of Devonian sandstone was found to be of interest for production of building raw material.

The fieldwork was undertaken in July1999 by Peer-R. Neeb, and Arnhild Ulvik, NGU. Thorbjørn Raadim, NOR Engineering A/S was also present during the field examination.

3. METHODS

3.1 Selection of areas

For the sake of completeness, a general description is included clarifying the criteria on which the selection of new, potential areas for extracting aggregate is based. Table 1 lists some important criteria [1].

Table 1. Criteria for large coastal aggregate plants

Criteria	Description
Location	Proximity to the sea, < 2-3 km
Reserves	Minimum 250 million tonnes
Sea depth/fjord width	Minimum 12 metres for ships of Panmax size, 300 m wide
Climatic conditions	Harbour and extraction site protected from bad weather
Density	Preferably less than 2.80 g/cm^3
Bedrock homogeneity	As homogeneous as possible
Bedrock quality	As good as possible; some minimum requirements must be met
Environmental aspects	Is the plant open to view? Distance to housing; pollution

When selecting new areas for the extraction of aggregate, the way in which the deposit will be worked will influence the location of the plant. Aggregate deposits are chiefly worked as open quarries. Occasionally, they are worked underground, in which case some of the criteria that have to be given priority, when surface working is to take place, can be ignored. Negative environmental consequences, such as spoiling the view, dust and noise, can be completely or more effectively limited when underground working takes place. An underground aggregate plant can be placed closer to a built-up area than an open quarry.

Deposits of the size we are considering, i.e. having an annual production of > 2-5 mill. tonnes, will probably be suitable for surface operation only. Calculations have been made which show that aggregate deposits with an annual extraction of the order of 1 mill. tonnes may be competitive using underground working relative to surface working [2].

The resources required for large aggregate plants with an annual production of the order of 2-5 mill. tonnes are a minimum of 250 mill. tonnes (50 years operation) [1]. Large coastal aggregate plants will probably experience lower annual production during a start-up phase, before gradually building up to full capacity. It is essential that the resources available are sufficient to enable production to be increased in the event of a future rise in demand. It may be mentioned that the first, and so far only large coastal aggregate plant in Europe, Glensanda on the north-west coast of Scotland, has reserves of 450 mill. tonnes. The annual production is 5 mill. tonnes, with plans to raise it to 15 mill. tonnes.

A topographical map will provide useful information when the location of a new deposit, which it is envisaged will be worked as an open quarry, is being considered. It is important, to consider the mode of operation right from the start so that areas may be found where an intended quarry can be accommodated to the topography to minimise environmental problems, above all the scenery being spoilt. Other important aspects will be the conditions for building a good harbour, and satisfactory maritime approaches and depth of the sea. The availability of other kinds of infrastructure, such as roads, power supply and settlements, may also be given priority. As regards the geology, areas with bedrock that can be assumed to have poor mechanical properties (in general, schistose, mica-rich rocks) and areas with a thick cover of superficial deposits should be avoided.

After an area has been selected in accordance with the above criteria, it is natural to investigate the presence of any evident land-use or environmental conflicts. It is useful to have a round of consultation when contact should be taken with the Environmental Division of the County Governor's Office, the County Council and neighbouring local authorities. These bodies are in possession of information which may, at an early stage, exclude areas from further consideration. Examples of this kind of information will be agricultural and forestry interests, already recorded ancient monuments, and considerations related to natural and cultural landscapes.

3.2 Field investigations

Field investigations of new aggregate deposits consist of bedrock and engineering geological mapping. The objective is to map parameters that are important for extraction and production of aggregate. The results will provide an overview of recorded variations in the properties and quality of the bedrock to avoid surprises being encountered in a possible operating phase.

The geological mapping entails recording and delimiting rock types. Other important parameters are the grain size, texture and homogeneity of the rocks. Structures, the frequency and direction of joints, surface weathering, radioactivity and, not least, mechanical and physical parameters are also mapped.

In connection with this project, fieldwork of this nature has been carried out. Since geological maps are available for the Gulestø area, the fieldwork was primarily concentrated around locating suitable places to take samples for mechanical investigations. The geology was appraised, but only with a view to judging the homogeneity within the relevant extraction areas.

The area which was examined rises evenly up to 225 metres above sea-level. The highest parts in the actual extraction zone are covered by morainic materials consisting mainly of large blocks. There is a locally densepine forest on the moraine, Figure 1. Exposures are first observed in the lower parts, close to the power lines. It is here that the sampling points are shown.

The road cutting along the whole extent show a massive and homogenous sandstone in the central part and towards the west, Figure 2. Towards the east the sandstones are somewhat more foliated.

Investigation of mechanical and physical properties involves some sampling. The extent of the sampling depends on variations in the geology of the area and qualitative differences which can be recorded by surface mapping of the rocks. Sampling is undertaken by "small-scale blasting" on the surface, usually down to a depth of 0.5 metres. To obtain sufficient material for the mechanical test analyses, about 60 kg are taken from each sampling site. The site at Gulestø is drilled to a depth of ca. 3.5 m. Pictures of the drill site are given in Figure 3. Figure 4 shows the blasted material from sample site 1. The second sample from Gulestø was collected from representative material along the whole cutting over a distance of almost a kilometre. The material has been mixed to give an average sample for the whole cutting.

Figure 1. Pine forest on moraine.

Figure 2. Road cutting in massive sandstone.

Figure 3. The drill site at Gulestø.

Figure 4. Blasted material from sample site.

4. ANALYSES AND REQUIREMENTS OF BUILDING RAW MATERIALS

The following analyses have been carried out at NGU: density, the Norwegian Impact Test (brittleness, flakiness, degree of compaction), ball mill, abrasion and Los Angeles test (see Appendices A1 - A8). The Polished Stone Value (PSV) test, has been carried out by Celtest Ltd. in Wales. Appendix A describes these laboratory methods.

The two areas have been characterised by hand-sized samples amounting to a total of about 60 kg. Prior to the mechanical testing, the samples were crushed using laboratory crushers under controlled conditions. The material was then sieved to the various grain fractions used for the different test methods. The demands placed on aggregates refer chiefly to material prepared in a full-scale crushing and screening plant. Investigations have, however, shown [3] that analytical results from samples taken from the production, "production samples", may deviate considerably from fresh samples taken in the field, also called "geological specimen samples". The production samples will be dependent upon how well the material has been prepared in the crushing and screening plant. Mechanical testing of geological specimen samples gives a more neutral evaluation of the "inherent properties" of the rock as compared with production samples. When preparation in an aggregate plant is optimal, it is assumed that the analytical results for production samples will be comparable with the results of geological specimen samples crushed under controlled laboratory conditions.

Material intended to be used as aggregate in Norway must fulfil the demands of the Norwegian Impact Test and the abrasion method. In the Norwegian Impact Test, a stone category is estimated on the basis of values determined for brittleness and flakiness. For some areas of use, demands are also placed on resistance to wear (Wear), or the ball mill value (Bm). It is intended that the newly introduced ball mill method will replace the abrasion method. Appendix C summarises the current quality requirements for Norwegian aggregates. Table 2 gives a simplified summary of the Norwegian requirements for aggregates for use in road construction.

Table 2.

Area of use	Type of road	St. categ.	Abr.	Wear	Bm
Surface	Road with specially high traffic load, ADT > 5000	≤ 1	≤ 0.40	≤ 2.0	≤ 6.0
"	Road with high traffic load, ADT 5000 - 15000	≤ 2	≤ 0.45	≤ 2.5	≤ 9.0
"	Road with moderate traffic load, ADT 3000 - 5000	≤ 2	≤ 0.55	≤ 3.0	≤ 11.0
"	Road with moderate traffic load, ADT 1500-3000	≤ 3	≤ 0.55	≤ 3.5	≤ 13.0
"	Road with little traffic, ADT < 1500	≤ 3	≤ 0.65	-	-
Foundation		≤ 4	≤ 0.75	-	-
Sub-foundation		≤ 5	≤ 0.75	-	-

Demands for stone category (St. categ.), abrasion value (Abr.), resistance to wear (Wear) and ball mill value (Bm) depending on the area of use. The table is simplified and is based on Appendix C.

In general, the demands placed by roads with a high traffic load should be fulfilled, whereas those for roads with little traffic must be met if a deposit is to be of interest for extraction. The

Norwegian Impact Test, abrasion method and ball mill method are also standard techniques in the other Nordic countries, except that testing is undertaken on somewhat different grain fractions.

Various testing methods are used elsewhere in Europe, but they often express the same mechanical loads as those resulting from the Norwegian and Nordic methods. Comparison shows that the correlation between the various testing methods is sometimes good [4]. The on-going CEN work (Comité Européen de Normalisation) has led to standardisation of the methods that are to apply for all EU/EFTA countries. The ball mill, Los Angeles and PSV are all approved as "CEN methods". Appendix D1 - D6 summarises the quality requirements for aggregates for some European countries.

Table 3 gives a simplified summary of the requirements for aggregates for road construction purposes in some European countries.

Table 3.

Country	Area of use	Type of road	LA	PSV
	Road surface	Motorways, special demands	< 16	> 65
England	"	Roads with normal traffic loads	< 25	> 55
	"	Roads with little traffic	< 30	> 45
	Foundation and sub-foundation		< 35	-
	Road surface	Motorway, special demands	< 15	> 55
Germany	"	Roads with normal traffic loads	< 20	> 50
	"	Roads with little traffic	< 30	> 43
	Foundation and sub-foundation		< 40*	-
	Road surface	Motorways, special demands	< 15	> 50
France	"	Roads with normal traffic loads	< 20	> 50
	"	Roads with little traffic	< 25	> 40
	Foundation and sub-foundation		< 30	-
	Road surface	Motorways, special demands	?	> 65
Netherlands	"	Roads with normal traffic loads	?	> 53
	"	Roads with little traffic	?	> 48
	Foundation and sub-foundation		?	-

*** Demand depends on rock type**

Demands regarding the Los Angeles value (LA) and the Polished Stone Value (PSV) for some European countries depending on the area of use. The table is simplified and is based on Appendix D.

In general, the demands for roads with a high traffic load should be fulfilled, whereas those for roads with little traffic must be met if a deposit is to be of interest for extraction.

Even though no demands are placed on the specific gravity of the rock, expressed as density, it should neither be too low nor too high (preferably < 2.80 g/cm^3). For certain purposes, such as large blocks for use in dykes, as heavy ballast, as material for covering oil pipelines on the sea floor, etc., demands on a minimum specific weight may be placed, but these are exceptional cases. The market share for special products with a high specific weight is relatively small.

5. RESULTS

5.1 Gulestø

5.1.1 Geology

The area has been mapped previously and is shown on the Måløy bedrock map, at a scale of 1:250 000 [5], which depicts the whole area as being dominated by Devonian sandstone.

5.1.2 Opportunities for extraction

A sample was taken from a fresh road cut and from a sampling point . The topography in the area makes it difficult to find the most suitable place for extraction based on quarry working, but a possible area is marked on the map in Figure 5. The distance to the sea and possibilities for constructing a good quay in the area are considered to be good.

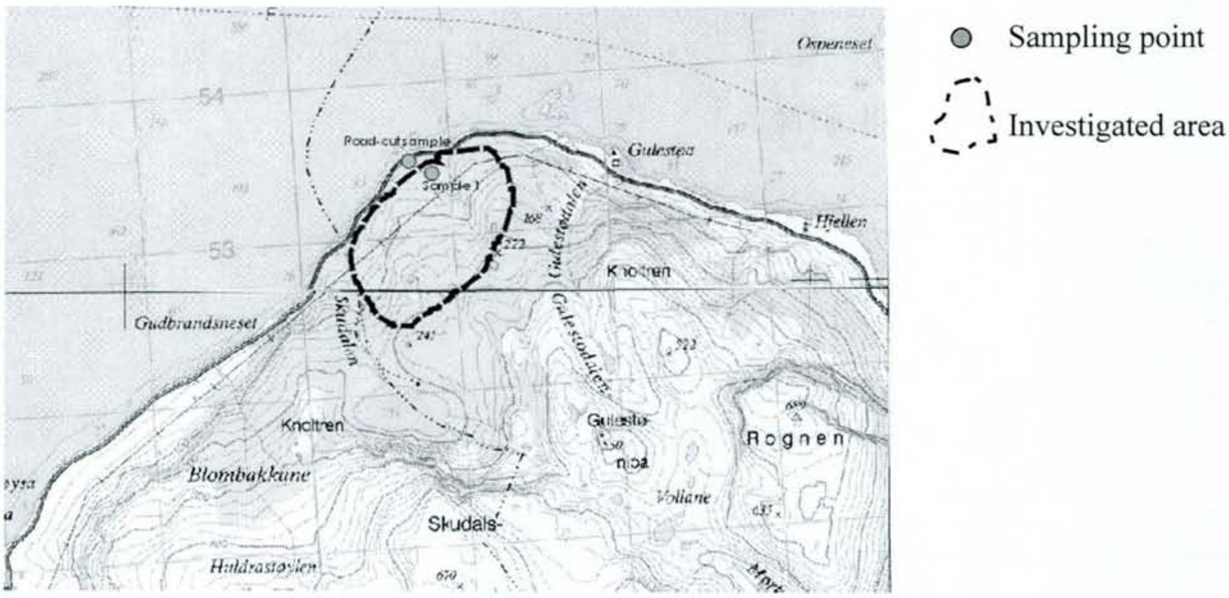


Figure 5. Gulestø, map sheets Bremanger 1118-4 and Florø 1118-3.

5.2 Results of analyses – appraisal

Two samples was taken at the location shown in Figure 5 and 8. The results of the thin-section and mechanical analyses are in Tables 4 and 5.

Table 4., Mineral content in % for sampling points of sandstones in Bremanger.

Sample	Grain size	Texture	Feld	Qtz	Ep	Mica	Carb	Chl	Misc
Gulestø (sample 1)	Fine grained	Granular	**24**	**40**	**15**	**5**	**6**	**5**	**5**
Gulestø (road cut)	Fine grained	Granular	**26**	**40**	**10**	**6**	**10**	**4**	**4**
Nesbø	Fine grained	Granular	10	55	10	7	10	5	3
Kjelkenes	Fine grained	Granular	25	50	10	4	3	3	5
Svelgen	Fine grained	Granular	15	50	8	7	10	8	2
Hjellen	Fine grained	Granular	10	60	12	10	1	5	2

Feld - feldspar, Qtz - quartz, Mica - mica, Ep - epidote, Carb - carbonate, Chl - chlorite, Misc - other minerals

Table 5. Mechanical and physical properties, Gulestø and other sampling points of sandstones in Bremanger. (Analytical results from Gulestø are given in bold type).

	Gulestø (sample 1)	**Gulestø (road-cut)**	Nesbø	Kjelkenes	Svelgen	Hjellen
Density	**2.74**	**2.74**	2.72	2.71	2.73	2.73
Degree of compaction	**0**	**0**	1	1	0	1
Brittleness	**31.5**	**32.2**	30.8	32.2	29.6	25.4
Flakiness	**1.42**	**1.41**	1.40	1.39	1.40	1.37
Stone category	**1**	**1**	1	1	1	1
Abrasion	**0.61**	**0.58**	0.70	0.50	0.61	0.57
Wear	**3.4**	**3.3**	3.9	2.9	3.3	2.8
Ball mill value	**12.5**	**12.2**	16.6	12.0	13.0	11.7
Los Angeles value	**12.9**	**12.4**	12.4	11.9	11.4	10.8
PSV	**58**	**57**	63	57	62	61

When compared with previous analyses of Devonian sandstones [6], the Gulestø samples fall within values that are normal for the sandstones in this district. The high PSV indicates that this rock type is one of the better ones analysed by NGU. In general, there would be little variation in the mechanical properties for sandstones from this area, but if the mineral content and grain size of the rock vary, changes in the mechanical properties must also be expected.

Figure 6 shows how the PSV varies with the content of softer minerals (carbonate, mica and chlorite) and hard minerals (quartz, feldspar and epidote). The PSV results correlate positively with increasing content of soft minerals (highest numerical value).

The abrasion value and PSV are compared in Figure 7. They have a negative correlation.

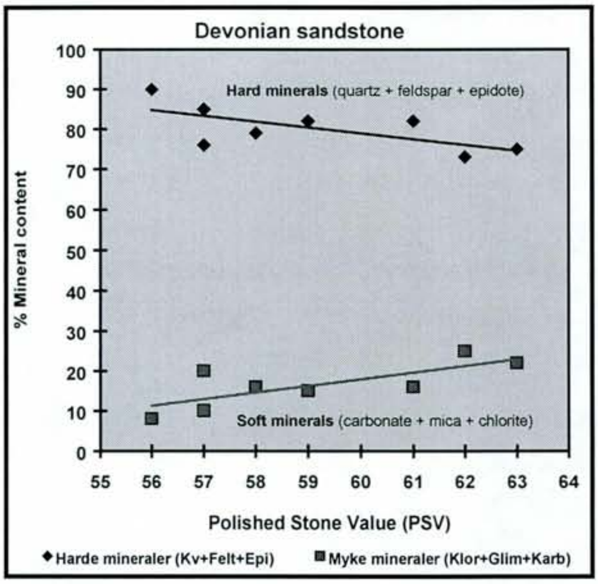


Figure 6. PSV and mineral content in %.

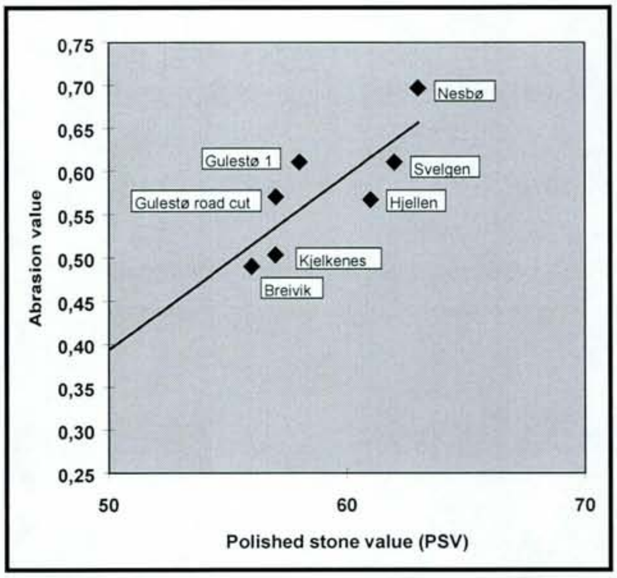


Figure 7. PSV and abrasion value.

5.2.1 Use as building raw material

Tables 6 and 7 give a suitability evaluation for the type of rock in this area relative to areas of use in several countries.

Table 6. Suitability evaluation for road construction purposes based on Norwegian demands

Area of use	Type of road	St. categ.	Abr.	Wear	Bm	Suitability evaluation
Surface	Road with specially high traffic load, ADT > 5000	+	-	-	-	Unsuitable
"	Road with high traffic load, ADT 5000 - 15000	+	-	-	-	Unsuitable
"	Road with moderate traffic load, ADT 3000 - 5000	+	-	-	-	Unsuitable
"	Road with moderate traffic load, ADT 1500-3000	+	-	+	+	Suitable
"	Road with little traffic, ADT < 1500	+	+	n.d.	n.d.	Suitable
Foundation		+	+	n.d.	n.d.	Suitable
Sub-foundation		+	+	n.d.	n.d.	Suitable

St. categ. - Stone category, Abr. - abrasion value, Wear - resistance to wear, Bm - ball mill value, + satisfies demands, - does not satisfy demands, n.d. - no demands (for demands, see Table 2). To attain the designation suitable, the demands for either the stone category, the abrasion value and the resistance to wear must be met, or just the stone category and the ball mill value

Table 7. Suitability evaluation for road construction purposes.

Country	Area of use	Type of road	**LA < 13**	PSV **57/58**	Suitability evaluation
	Road surface	Motorways, special demands	+	-	Unsuitable
England	"	Roads with normal traffic loads	+	+	**Suitable**
	"	Roads with little traffic	+	+	**Suitable**
	Foundation and sub-foundation		+	n.d.	**Suitable**
	Road surface	Motorways special demands	+	+	**Suitable**
Germany	"	Roads with normal traffic loads	+	+	**Suitable**
	"	Roads with little traffic	+	+	**Suitable**
	Foundation and sub-foundation		+	n.d.	**Suitable**
	Road surface	Motorways, special demands	+	+	**Suitable**
France	"	Roads with normal traffic loads	+	+	**Suitable**
	"	Roads with little traffic	+	+	**Suitable**
	Foundation and sub-foundation		+	n.d.	**Suitable**
	Road surface	Motorways, special demands	?	-	Unsuitable
Netherlands	"	Roads with normal traffic loads	?	+	? / **Suitable**
	"	Roads with little traffic	?	+	? / **Suitable**
	Foundation and sub-foundation		?	n.d.	? / **Suitable**

To attain the designation Suitable all the demands must be met. Demands which are almost met are given the code - / (+) and are evaluated as Unsuitable / (Suitable). LA - Los Angeles value, PSV - Polished Stone Value, + satisfies the demands, - does not satisfy the demands n.d. - no demands, ? - possible demands not known (for demands, see Table 3).

To be used for concrete, the material is evaluated as suitable to unsuitable in accordance with both Norwegian demands (Appendix C4) and demands in other European countries (Appendix D7). The reservation must be made that the sandstone may prove to give an alkaline reaction when used as an aggregate in concrete.

6. OVERALL APPRAISAL OF THE RESULTS

To be able to judge the quality of the rock, they have been verbally ranked in Table 7. This ranking is based on the suitability evaluation for road construction and concrete, in keeping with the following categories, Table 8.

Table 8. Suitability evaluation for road construction and concrete in some European countries.

Quality of rock	Suitability evaluation
Very good	Suitable for all road construction purposes and for concrete
Good	Suitable for at least roads with normal and high traffic loads, and for concrete
Moderate	Suitable for at least roads with light traffic loads, and for concrete
Poor	Suitable for foundations and sub-foundations, and for concrete
Very poor	Unsuitable for road construction purposes and concrete

Large-scale extraction of aggregates requires sufficiently large volumes of reserves.

For large-scale working, areas with raw material that are homogeneous as possible are to be preferred. In this respect, all the areas investigated are favourable.

For most uses, the density of the raw material should be as low as possible, preferably < 2.80 g/cm^3. Hence, it is favourable within the areas of sandstone.

Because requirements vary with regard to both the area of use and the European country concerned, an overall appraisal of the quality of the rock types is difficult to make. In general, the quality is considered **good** for Gulestø relative to the quality demands placed on building raw materials in England, Germany, France, the Netherlands and Norway.

The results of the analyses show that the sandstones at Gulestø have low Los Angeles values, thus indicating good properties for use in road surfaces in Europe. For Norwegian purposes, these sandstones have somewhat high abrasion and ball mill values, and therefore only fulfil the demands for roads with moderate and light traffic loads.

7. FURTHER INVESTIGATIONS AND PROPOSAL FOR AN EXTRACTION PLAN

A proposal has been worked out for an aggregate production plant with crushing and screening facilities by the road and the sea. The tonnage at this facility is estimated at 3 million tonnes, whereas the tonnage in the main quarry is estimated at 165 million tonnes (Figure 8). There are possibilities for extending the quarry in a southerly direction.

It is proposed that 3D modelling should be undertaken to obtain a better picture of how such a quarry appears in the landscape, and eventually to find better alternative solutions to screen the quarry from public. Figures 9, 10, 12 and 13 give us some examples of how a quarry would look like from two different positions, and at two different levels.

Before such a quarry is opened it is recommended that diamond drilling (with core retention) should be carried out in the centre of the quarry down to a base level (5 m. contour). On the core materials a point loading test should be carried out; this is a method that will give information on rock strength at depth. The method can also indicate if there is weathering or jointing in the uppermost part. In addition one will obtain an indication of the degree of homogeneity at depth.

In addition to core-drilling, it is proposed that two further sites should be sampled and laboratory tested, within the delimited area, to check whether or not material has the anticipated homogeneity (mineral and PSV variation).

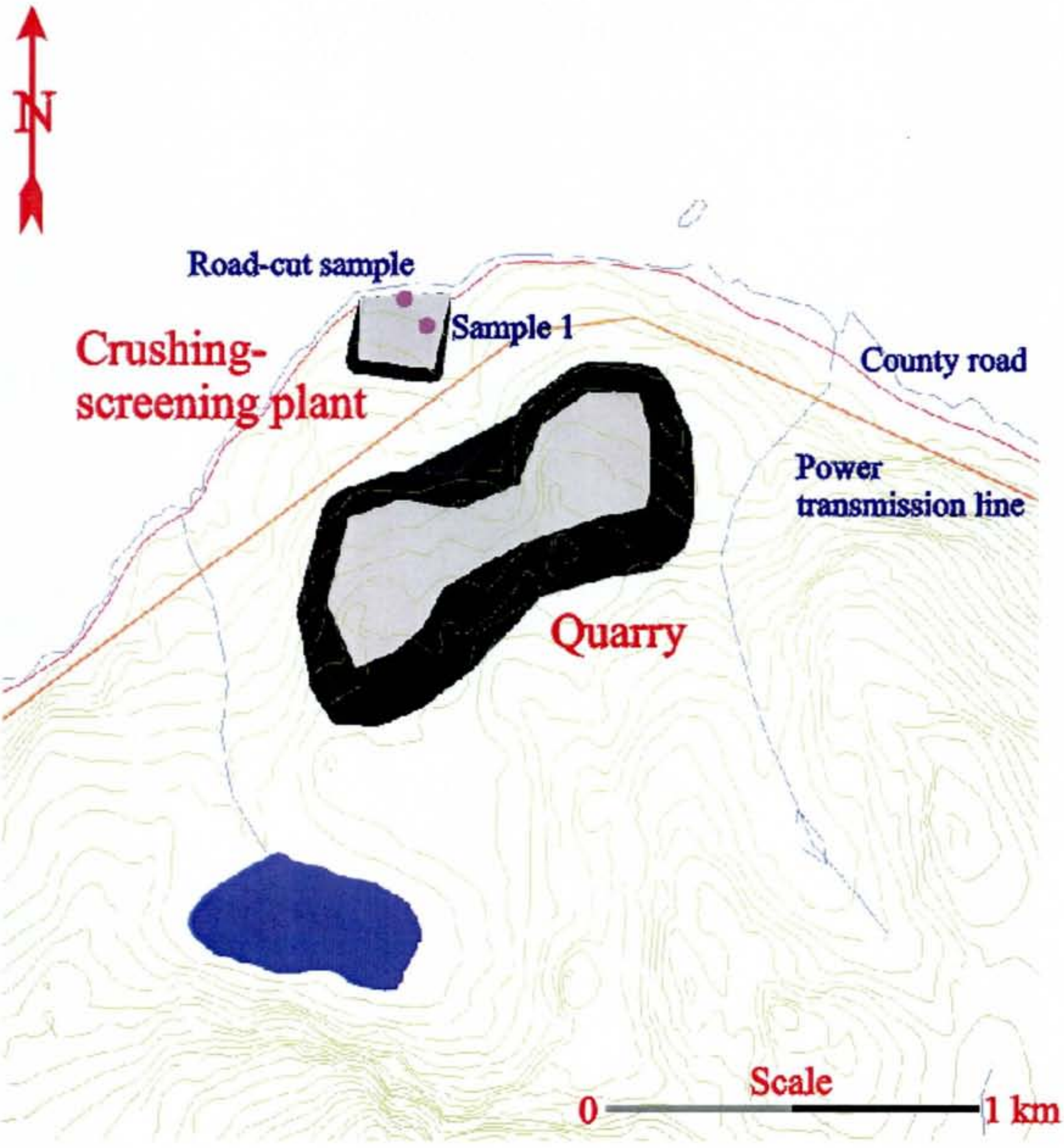
Because the highest parts in the actual extraction zone are covered by morainic materials, it would be of interest to carry out seismic refraction measurements to ascertain the sediment thickness.

It may also be necessary to carry out mapping of lithological /deformational variations of the Devonian sandstones.

It may also be necessary to carry out geological map pung at a scale 1:5000 in the area.

NGU

Proposal for extraction plan
Gulestø - Bremanger kommune



Tonnage estimation

Quarry	: ~165 mill.metric tonnes
Crushing-/screening plant	: ~ 3 mill.metric tonnes

(Estimated using a rock density of 2,74 g/cm^3)

E. Erichsen - aug. 1999

Figure 8.

Eyolf Erichsen, NGU, has made a 3D model of the Gulestø area. Figures 9 and 10 show how a quarry will look like from Nesbø, in perspective and at sea level. At sea level a quarry will be screened from view.

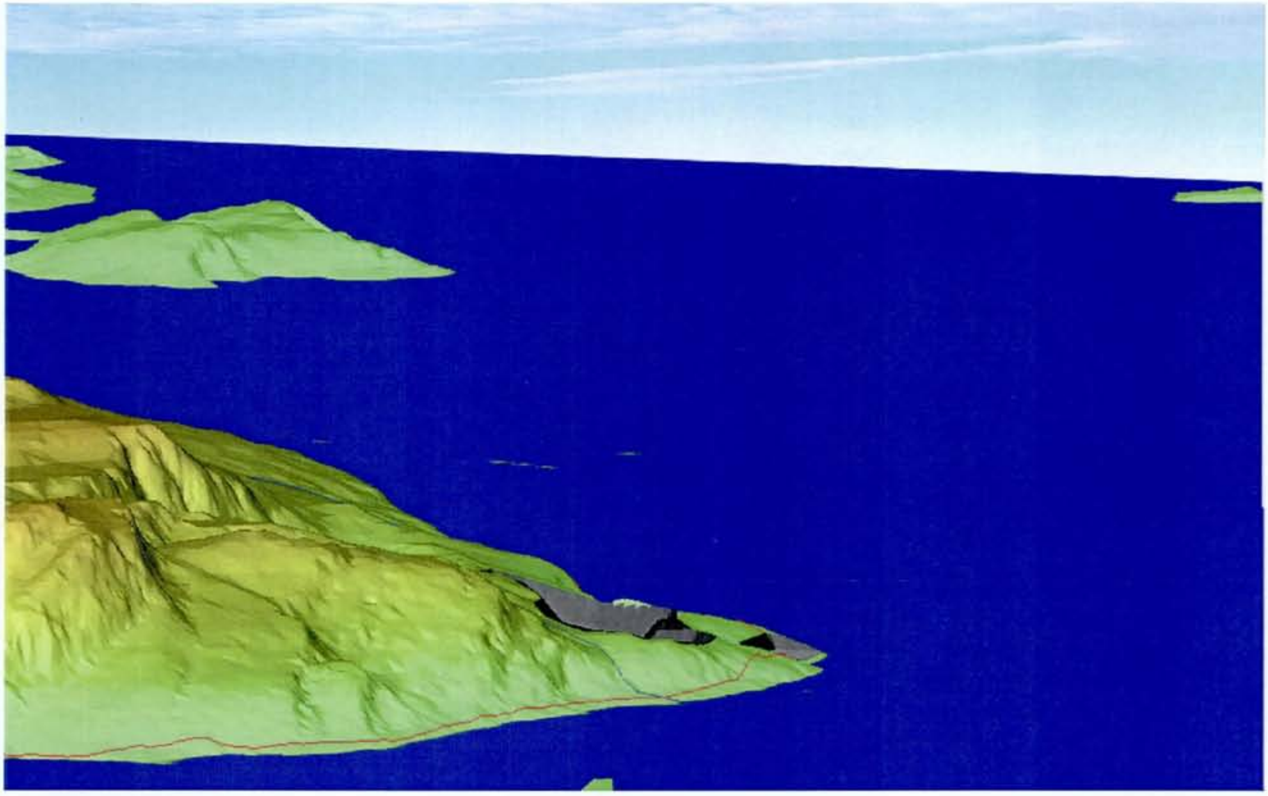


Figure 9. View from Nesbø of Gulestø in perspective.

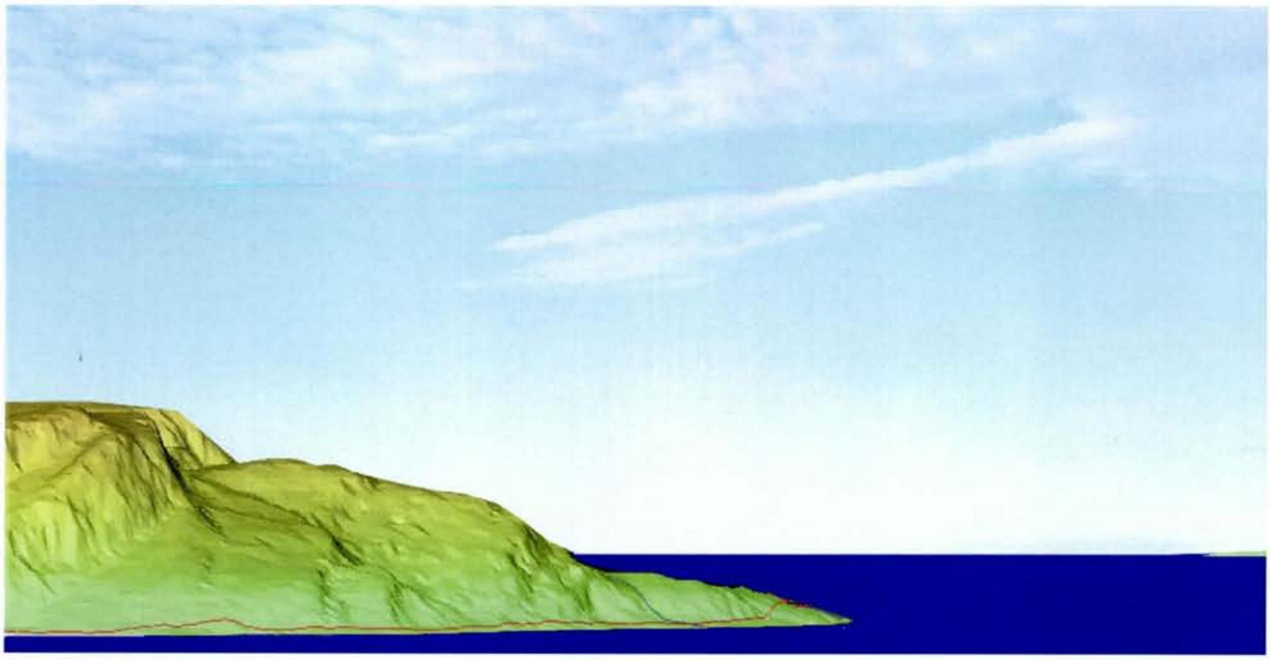


Figure 10. View from Nesbø of Gulestø at sea level.

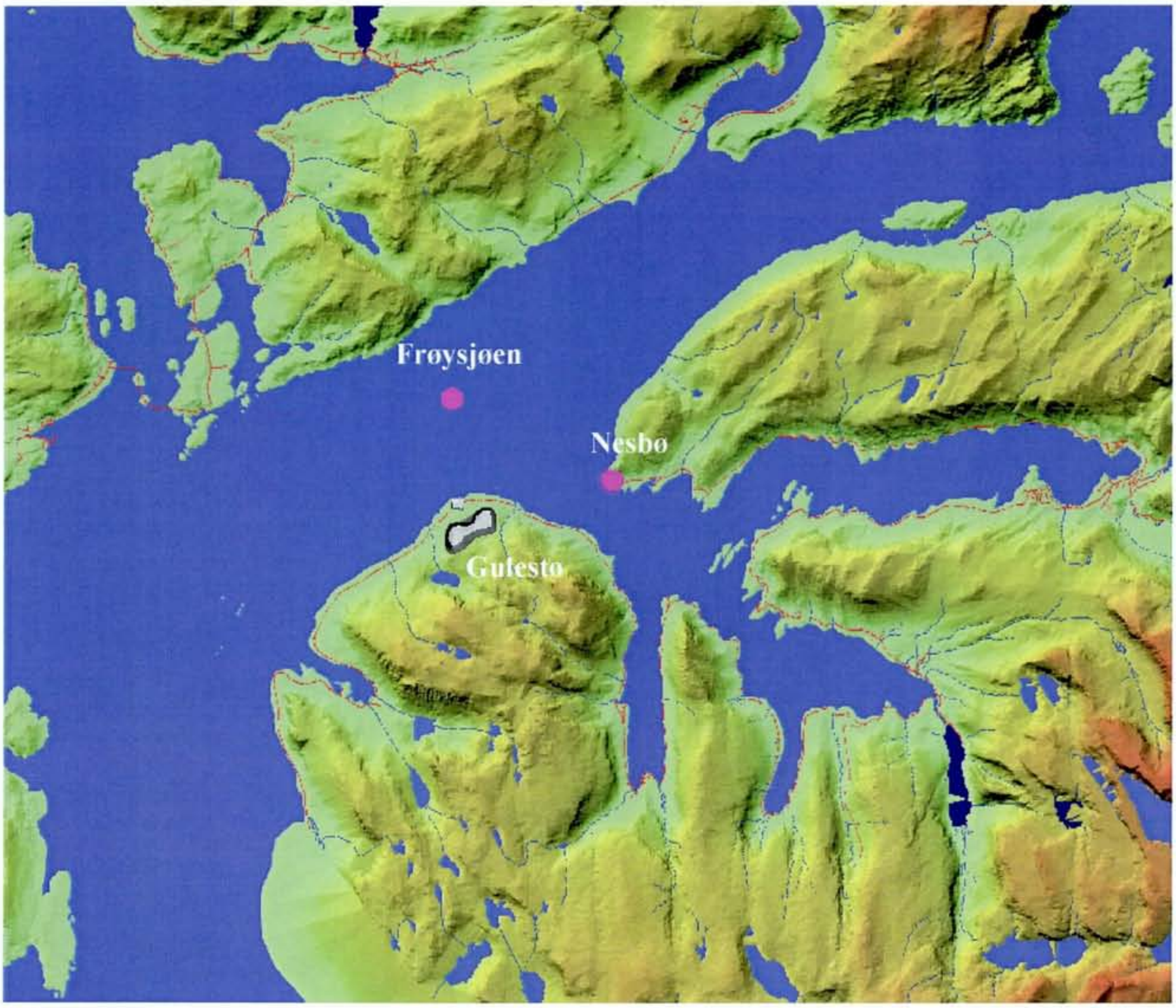


Figure 11. Map of Gulestø, Nesbø and Frøysjøen.

Figure 11 shows where the Gulestø area, Nesbø and Frøysjøen are. Figures 12 and 13 show how a quarry will look like from the sea side, at the position marked at the map. It will be difficult to screen the quarry from this position.

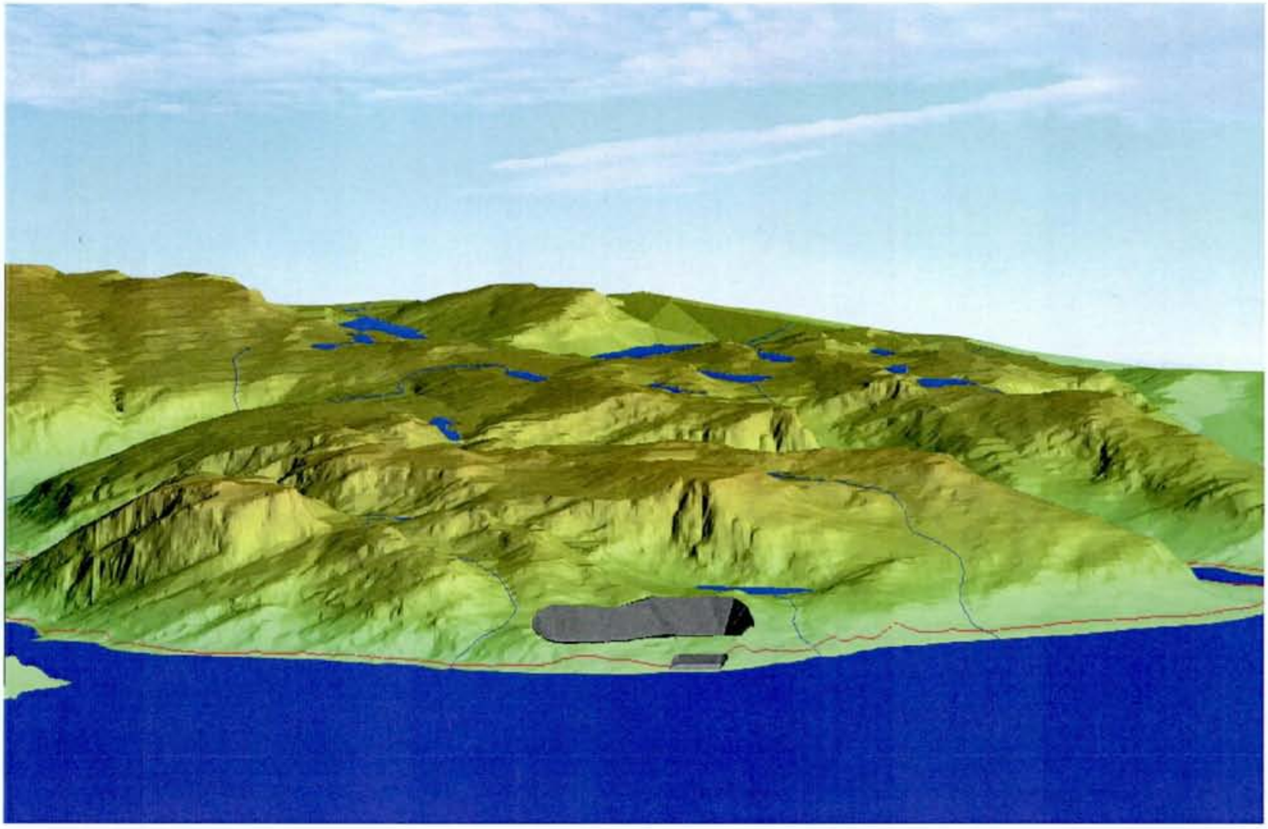


Figure 12. View from the fjord (Frøysjøen) of Gulestø in perspective.

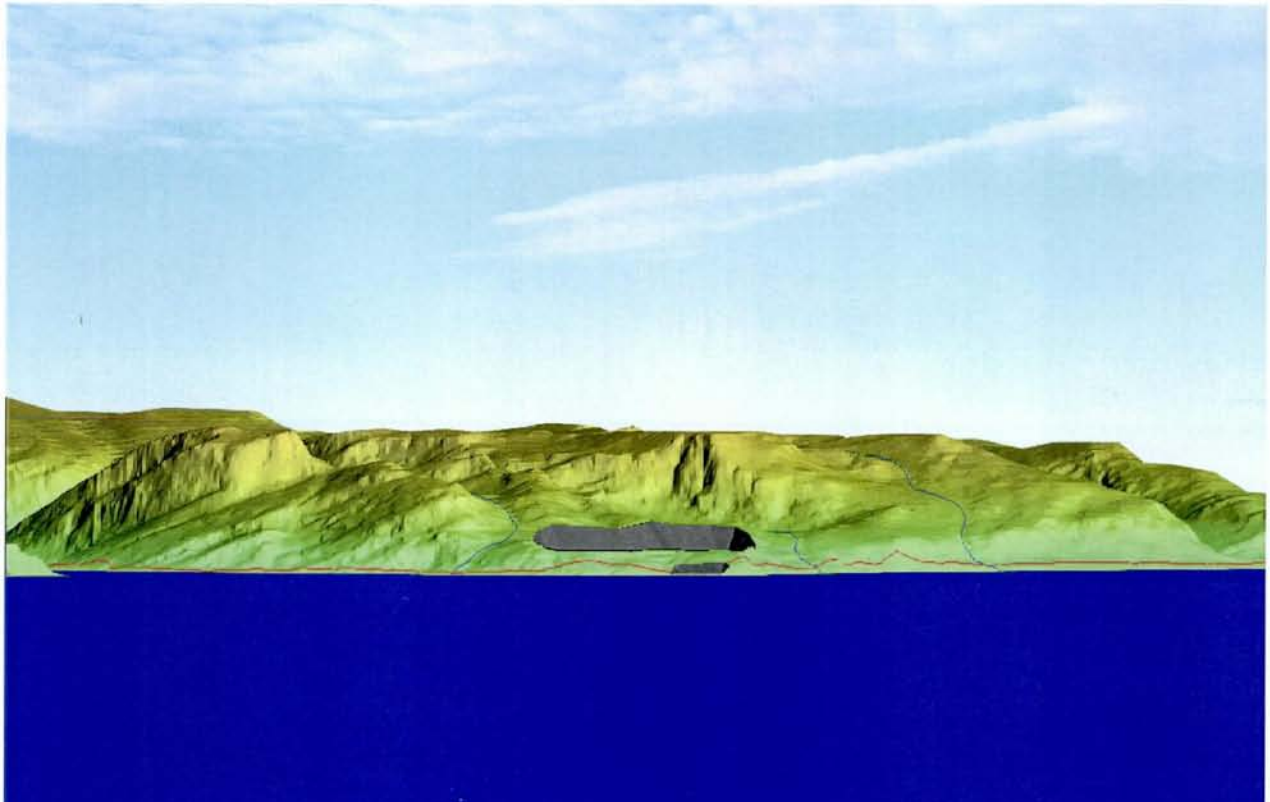


Figure 13. View from the fjord (Frøysjøen) of Gulestø at sea level.

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Vedlegg nr. 1

NGU
Norges geologiske undersøkelse

Mekaniske egenskaper

Sprøhet / flisighet / abrasjon
kulemølle / Los Angeles / PSV

Gulestø (road-cut)

Lab.prøve nr.: 990046

KOMMUNE :	Bremanger	KOORDINATER :	
KARTBLADNR. :		DYBDE I METER :	
FOREKOMSTNR.:		UTTATT DATO :	07.07.1999
		SIGN. :	

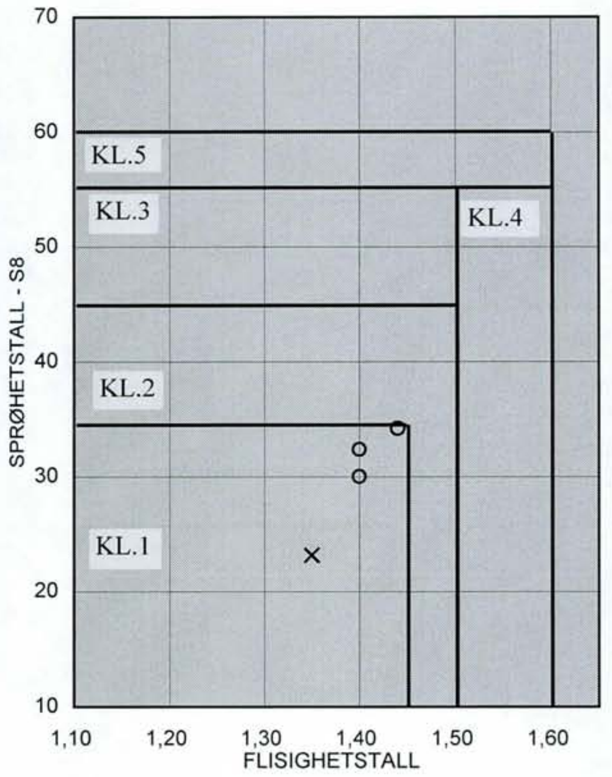
Visuell kvalitetsklassifikasjon :

Antall korn vurdert stk.	Meget sterke %	Sterke %	Svake %	Meget svake %

Mekaniske egenskaper :

Kornstørrelse mm	8 - 11,2				11,2 - 16	
Tegnforklaring	o	o	o	x		
Flisighetstall-fli	1,40	1,40	1,44	1,35	1,35	1,37
Flisighetsindeks-FI	22	21	26	13	14	19
Ukorr. Sprøhetstall-S0	30,0	32,4	34,2	23,2		
Pakningsgrad	0	0	0	0		
Sprøhetstall-S8	30,0	32,4	34,2	23,2		
Materiale < 2mm-S2	4,4	4,8	4,5	3,4		
Kulemølleverdi, Mv					11,9	12,5

Laboratorieknust i %: 100	% andel 8-11,2 av tot.mengde: 21,1
Avg fli-FI-S8; 8-11,2: 1,41 23 32,2	Middel S2 : 4,6
Avg fli-FI-Mv; 11,2-16: 1,36 17 12,2	PSV : 57
Abrasjonsverdi-a: 0,55 0,60 0,55	Middel : 0,57
Sa-verdi (a * sqrt S8): 3,2	Densitet : 2,74
Flis.tall/-indeks; 10-14: 1,34 / 20,0	LA-verdi : 12,4



Merket x : slått 2 ganger (omslagsverdi)

BERGARTS BESKRIVELSE: Bergart: Sandstone

Mineralinnhold: 40% quartz, 26% feldspar, 4% chlorite, 10% carbonate, 6% mica, 10% epidote, 4% other minerals.

Reaksjon med HCL:

Sted:	Dato:	Sign.:
Trondheim	20.09.1999	A. Ulvik

Vedlegg nr. 2

NGU Norges geologiske undersøkelse

Mekaniske egenskaper

Sprøhet / flisighet / abrasjon
kulemølle / Los Angeles / PSV

Gulestø (sample 1)

Lab.prøve nr.: 990047

KOMMUNE : Bremanger
KARTBLADNR. :
FOREKOMSTNR.:

KOORDINATER :
DYBDE I METER : 3.5 m
UTTATT DATO : 07.07.1999
SIGN. :

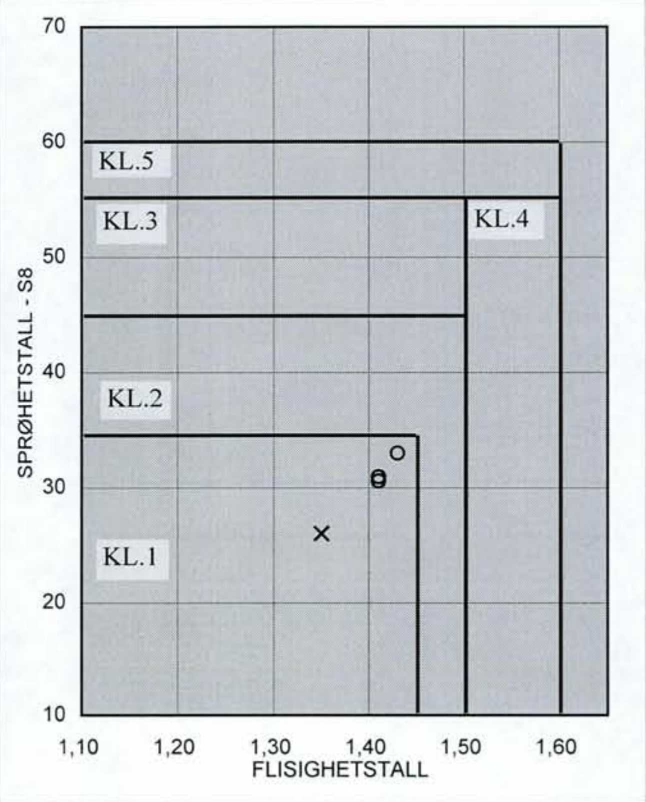
Visuell kvalitetsklassifikasjon :

Antall korn vurdert stk.	Meget sterke %	Sterke %	Svake %	Meget svake %

Mekaniske egenskaper :

Kornstørrelse mm	8 - 11,2				11,2 - 16	
Tegnforklaring	o	o	o	x		
Flisighetstall-fli	1,41	1,41	1,43	1,35	1,32	1,31
Flisighetsindeks-FI	21	23	24	14	14	14
Ukorr. Sprøhetstall-S0	30,6	31,0	33,0	26,1		
Pakningsgrad	0	0	0	0		
Sprøhetstall-S8	30,6	31,0	33,0	26,1		
Materiale < 2mm-S2	4,8	4,6	4,2	3,5		
Kulemølleverdi, Mv					12,4	12,6

Laboratorieknust i %: 100		% andel 8-11,2 av tot.mengde: 21,0	
Avg fli-FI-S8; 8-11,2:	1,42 23 31,5	Middel S2 :	4,5
Avg fli-FI-Mv; 11,2-16:	1,32 14 12,5	PSV :	58
Abrasjonsverdi-a:	0,63 0,57 0,62	Middel :	0,61
Sa-verdi (a * sqrt S8):	3,4	Densitet :	2,74
Flis.tall/-indeks; 10-14:	1,32 / 15,9	LA-verdi :	12,9



Merket x : slått 2 ganger (omslagsverdi)

BERGARTS BESKRIVELSE: Bergart: Sandstone

Mineralinnhold: 40% quartz, 24% feldspar, 5% chlorite, 5% mica, 6% carbonate, 15% epidote and 5% other minerals

Reaksjon med HCL:

Sted:	Dato:	Sign.:
Trondheim	20.09.1999	A. Ulvik

*** Norwegian Impact Test (brittleness and flakiness)**
*** Abrasion**
*** Resistance to wear**
*** Ball mill**
*** Los Angeles**
*** Polished Stone Value (PSV)**
*** Thin section**
*** Siever's J value**
*** Wear value**
*** Drilling Rate Index (DRI)**
*** Bit Wear Index (BWI)**

Norwegian Impact Test (brittleness and flakiness)

The ability of stone to resist mechanical impact stress can be determined by, for instance, the Norwegian Impact Test. This method is widely used in the Nordic countries (the way the test is carried out varies somewhat from country to country) and can to some extent be compared with the British 'aggregate impact test', the German 'Schlagversuch' and the American 'Los Angeles test'.

The Norwegian Impact Test consists of the crushing of a specific fraction, 8.0-11.2 mm, of gravel or aggregate of known grain shape in a drop apparatus. The apparatus consists of a mortar in which the test material is exposed to the impact of a 14 kg weight falling 20 times from a height of 25 cm. The proportion of the test material whose grain size after crushing is less than the minimum grain size of the original fraction, in this case 8.0 mm, is called the uncorrected brittleness value (S_0). This value is corrected for the degree of compaction in the mortar after the impact, permitting the **brittleness value (S_8)** to be calculated.

The average grain shape of the material is expressed by the **flakiness value**, which is a physical property indicating the relationship between the mean width and thickness of the grains. The flakiness test is performed as part of the Norwegian Impact Test and is determined on the same sieved grain-size fraction as the brittleness value. Flakiness verifications may, in addition, be made on any fractions desired. The width is determined on a sieve with a square mesh and the thickness on a sieve with a rectangular mesh. The method is used for both natural gravel and aggregate.

The results of the Norwegian Impact Test may vary from laboratory to laboratory, but the apparatus used has been reasonably well standardised since 1988. Unless otherwise stated, the brittleness value is given as an average of three separate measurements.

The material is usually tested twice in the drop apparatus. The brittleness value for the repeated impact, the repeated impact value, expresses the resistance of the material to repeated impact stress. The repeated impact value often reflects the improvement in quality which can be achieved by employing several stages of crushing in a crushing mill.

Stone is classified into stone categories based on the results of the Norwegian Impact Test. Five categories are recognised, depending on the brittleness and flakiness values.

Stone category	Brittleness	Flakiness
1	≤ 35	≤ 1.45
2	≤ 45	≤ 1.50
3	≤ 55	≤ 1.50
4	≤ 55	≤ 1.60
5	≤ 60	≤ 1.60

Classification of stone materials according to the Norwegian Impact Test. Stone category 1 is best and 5 is worst.

The brittleness and flakiness results may vary, depending on how the material has been sampled and handled prior to the Norwegian Impact Test itself. It is either collected as geological-specimen samples (hand-sized specimen of rock), or taken from a specific fraction prepared in a crushing mill (production sample).

Hand-specimen sampling is often employed when new areas that are of interest for extracting rock are being investigated. The sample is usually taken from a blasted road cut, or is blasted from a rock exposure. In both cases, the material will be exposed to crushing in connection with the blasting. Occasionally, hand-specimen samples are taken without them having been exposed to blasting. This occurs, for example, when a sample is taken from a scree, or struck directly off an exposure with a sledgehammer. In such cases, the rock must lack surface weathering. Hand specimens are always crushed in laboratory mills before undergoing the Norwegian Impact Test itself.

Hand-specimen sampling may also be carried out in an aggregate plant, but it is generally of greater interest to investigate the quality of the material after it has been through the crushing and screening plant (production samples). In the crushing plant, it is usual to crush the material in several stages. This improves its quality because it attains a more cubic grain shape (lower flakiness value), and also gives a better brittleness value. This processing effect depends to some extent on the type of rock.

Production samples must be handled in accordance with the following guidelines:

a) For screened material with a stated upper grain size of less than 22 mm
the Norwegian Impact Test is performed on the 8.0-11.2 mm fraction screened from the product concerned, provided that that fraction comprises at least 15% of the product. If this requirement cannot be fulfilled, the Norwegian Impact Test is performed according to alternative b).

b) For screened material with a stated upper grain size in excess of 22 mm
the Norwegian Impact Test is performed on the 8.0-11.2 mm fraction of the product concerned sieved from material crushed in the laboratory.

In addition, in the case of production samples, verification of flakiness must be undertaken on the coarse fraction of plant-produced material in one of the following fractions: 11.2-16.0 mm, 16.0-22.4 mm, 22.4-32.0 mm, 32.0-45.2 mm or 45.2-64.0 mm. A fraction must be chosen which corresponds to at least 15% of the product and which is as close as possible to the stated upper grain-size limit of the product. Material that is produced must maintain a flakiness value > 11.2 mm.

Abrasion

Abrasion, or the **abrasion value**, expresses the abrasive resistance to wear or resistance to scratching, of the material. The abrasion method is a Nordic method (the way the test is carried out varies somewhat from country to country) evolved from the British aggregate abrasion test. It is chiefly used for quality appraisal of aggregate for asphalt wearing surfaces on roads with an annual daily traffic (ADT) load in excess of 1500 vehicles. Maximum abrasion values have also been introduced for aggregate to be used for roadbase and sub-base courses.

A representative selection of aggregate grains in the 11.2-12.5 mm fraction is cast on a square plate (10x10 cm) which is pressed with a given weight against a rotating disc carrying a standard grinding powder. The wear, or abrasion, is defined as the volume loss of the sample expressed in cubic centimetres.

The following classification is used:

< 0.35	**very good**
0.35-0.45	**good**
0.45-0.55	**moderate**
0.55-0.65	**poor**
> 0.65	**very poor**

Resistance to wear

The brittleness, flakiness and abrasion values are measured to determine the suitability of stone as aggregate for asphalt road surfaces. The resistance of the material to wear from studded tyres, called the resistance to wear (WR value) is expressed as the product of the square root of the brittleness value (S_8) and the abrasion value.

The following classification is used:

< 2.0	**very good**
2.0-2.5	**good**
2.5-3.5	**moderate**
3.5-4.5	**poor**
> 4.5	**very poor**

Ball mill

The ball mill method, like the abrasion method, expresses the resistance to wear of the stone. It has been introduced as a Nordic method in connection with the European standardisation programme for aggregates (CEN/TC 154). It is designed to determine the resistance of aggregate to wear deriving from studded tyres. The method should in due course replace the abrasion method.

Briefly, the method is as follows. 1 kg of stone in the 11.2-16.0 mm fraction is rotated in a drum for 1 hour at 5400 revolutions per hour together with 7 kg of steel balls and 2 litres of water. The drum has a specific shape and is equipped with three devices which raise and mix its contents as it rotates. The stone is exposed to both impact and wear, but mainly wear. After the rotation period, the material is wet sieved and dried. After weighing, the proportion that passes through a 2 mm square-mesh sieve is calculated. This expresses the wear, and is termed the **ball mill value (K_m).**

The following classification is used:

≤ 7.0	**category A**
≤ 10.0	**category B**
≤ 14.0	**category C**
≤ 19.0	**category D**
≤ 30.0	**category E**
No demand	**category F**

Category A is best and category F worst.

Los Angeles

The Los Angeles test expresses the ability of material to resist both impact and wear. The method is originally American, but has been in use for many years in several European countries, for instance by the Norwegian State Railways (NSB) in Norway. It can be performed using the standard American procedure, ASTM C131 (fine aggregate) and ASTM C535 (coarse aggregate), or the new European CEN procedure prEN 1097-2, §4.

When the CEN procedure is used, 5 kg of stone in the 10.0-14.0 mm fraction are rotated in a drum together with 11 steel balls. The inside of the drum is equipped with a steel plate which, as the drum revolves, lifts the material and the steel balls up before dropping them again. After about 15 minutes and 500 revolutions, the material is removed, wet sieved and dried. After weighing, the proportion that passes through a 1.6 mm square-mesh sieve is calculated. This expresses the mechanical load and is called the **Los Angeles value (the LA value).**

The following classification is used:

≤ 15.0	**category A**
≤ 20.0	**category B**
≤ 25.0	**category C**
≤ 30.0	**category D**
≤ 40.0	**category E**
≤ 50.0	**category F**
No demand	**category G**

Category A is best and category G worst.

Polished Stone Value (PSV)

PSV is a British method used for recording the resistance to polishing of aggregates that are to be used in road surfaces. In central Europe, it is desirable to have road surfaces with a high resistance to friction to avoid them becoming slippery. This is not a problem in Nordic countries because the studded tyres used in winter roughen the surface of the aggregate in the surface layer.

The test procedure requires that 35 to 50 particles of a specific grain fraction, < 10 mm in a square-mesh sieve and > 7.2 mm in a rectangular-mesh sieve are cast on a convex, rectangular sheet (90.6 x 44.5 mm). 12 test sheets (4 for each sample) and 2 control sheets are mounted on a road wheel that is itself mounted vertically on a polishing machine. The wheel rotates for 3 hours at 315-325 revolutions per minute. It is loaded by a wheel consisting of compact rubber that is rotated in the opposite direction from the road wheel.

Water and grinding powder are applied to the rubber wheel. After the test sheets have been in the polishing machine for the allotted time, the polishing resistance is measured with a pendulum apparatus. A pendulum arm is brushed across the test sheet giving a reaction on a calibrated scale. This reaction is the friction coefficient, stated as a percentage and also called the PSV value.

The following classification is used:

≥ 68.0	**category A**
≥ 62.0	**category B**
≥ 56.0	**category C**
≥ 50.0	**category D**
≥ 44.0	**category E**
No demand	**category F**

Category A is best and category F worst.

Thin section

The term thin section is used for a thin slice of a rock that is glued to a glass slide. This forms the basis for the microscopic determination of minerals and their relative occurrence. When polarised light passes through the transparent slice, which is usually approximately 0.020 mm thick, the various minerals will be identifiable in the microscope owing to their characteristic optical properties.

The distribution of the minerals, along with the visual appraisal of structures in the terrain, form the basis for deciding the rock type. The microscopic examination also permits the study of internal textures, the shape and size of mineral grains, alteration phenomena and the mode of formation of the rock, etc.

Special textures can be observed, such as microfractures between the minerals, or rod-shaped feldspar grains which function as a kind of armour in an otherwise granular groundmass (ophitic texture). Foliation is another term which is often used in rock descriptions. That a rock is foliated means that the constituent minerals have a preferred planar axial orientation, or are concentrated in narrow, parallel layers or laminae. The grain size of the minerals is divided on the following scale:

< 1 mm - fine grained
1-5 mm - medium grained
> 5 mm - coarse grained

A thin section usually covers about 5 square centimetres. The result of one thin-section analysis is therefore rarely fully representative of the rock.

Siever's J value

The Siever J value of a rock is an expression of the resistance of the rock to scratching with hard metallic tools. A sawn sample of the rock is exposed to a rotating drill of hard metal under specific conditions. The Siever J value is defined as the depth of a hole measured in mm. The method has been devised to provide a general appraisal of how easily a rock can be drilled.

Wear value

The wear value of a rock is a measure of its ability to wear the hard metal of a drill edge. The rock is crushed to powder with a grain size of < 1 mm. The powder is placed on a rotating steel sheet in a special apparatus. A piece of hard metal is pressed against the sheet and is exposed to a wear load. The wear value derives as the loss of weight in milligrams for a sample of hard metal.

Drilling Rate Index (DRI)

Using the brittleness value and the Siever J value, it is possible to calculate the expected rate at which a particular rock can be drilled. A high figure for the DRI (drilling rate index) indicates a rock that is easy to drill, whereas a low drilling rate index suggests the opposite. For lightweight hammer drills, it has been shown that the drilling rate can be put at about 0.6 * DRI (cm/min).

The following classification is used:

< 32	**Very low**
32-43	**Low**
43-57	**Moderate**
57-75	**High**
> 75	**Very high**

Bit Wear Index (BWI)

The expected wear on a hammer drill bit (chisel edge) can be calculated on the basis of the wear value and the Drilling Rate Index (DRI). A high BWI (bit wear index) suggests very much wear and *vice versa*. The relationship between the BWI and wear measured in the field is logarithmic.

The following classification is used:

<18	**Very little**
18-28	**Little**
28-38	**Moderate**
38-48	**Much**
>48	**Very much**

*** Grain size distribution analysis**
*** Counting rock and mineral particles**
*** Humus and sediment determination**
*** Trial casting**

Grain size distribution analysis

Grain size distribution analysis shows how the grain sizes are distributed through the sample. The method is carried out in accordance with the analysis regulations drawn up by the Directorate for Public Roads and Norwegian Standard 427A part 2.

An appropriate amount of material pre-dried in a drying cabinet is dry sieved in a prepared set of sieves with a square mesh of defined dimensions. NGU normally employs a set of sieves with the following mesh dimensions::

(64) - (32) - 16 - 8 - 4 - 2 - 1 - 0.5 - 0.25 - 0.125 and 0.063 mm.

The uppermost sieve is usually 16 mm, but when the grain size distribution of coarser fractions is to be determined an uppermost sieve of 32 or maybe even 64 mm is used In the latter case, a considerably larger sample must be available. After being sieved, the material on each sieve is weighed and the figure is converted into a percentage of the total sediment sample.

The grain-size distribution of fine-grained material (material finer than sand - 0.063 mm) is determined by elutriation.

Grain size distribution analysis is vital when the material is to be evaluated as building raw material. The various areas of use have different requirements as regards grain size grading.

Counting rock and mineral particles

The objective of this procedure is to clarify the composition of rock and mineral particles, and the physical state, surface qualities and, in some cases, grain shape and degree of rounding of the material. Such counting is required when it is necessary to document the suitability for purposes demanding high quality material. It is also invaluable for undertaking initial appraisal and ranking of deposits. In many cases, the results can provide valuable information

about the way a deposit was formed. The counting is performed on selected grain sizes in the gravel and sand fractions. About 100 grains are split off for counting. The classification is done visually, using a microscope. While the coarse fractions are being counted, the ability of the grains to withstand scratching is tested with a steel spatula. Hydrochloric acid is used to identify limestone and a magnet to recognise magnetite.

X-ray analysis, differential thermal analysis, or chemical analyses are performed on rare occasions on powder preparations of the samples.

Gravel fraction
Rock particles in the samples are divided or collected into groups which are of significance for the suitability of the material as aggregate for purposes demanding high-quality material, and which it is practicable to reliably identify during the counting process. It is particularly important to clarify the content of soft, mechanically weak and weathered rock particles which will reduce the value of the material as aggregate in various constructions. The following divisions are employed:

Very strong particles
Strong particles
Weak particles
Very weak particles

For instance, the presence of schist, phyllite, porous limestone, sulphide ore and perhaps other impurities will be detrimental. A genetic categorisation is required to be able to identify rocks and minerals which will have an undesirable or detrimental effect on constructions.

Sand fraction
Mineral grains in the sand fraction are usually divided into two or three groups. This is the division usually followed:

1. Light-coloured grains
Mostly feldspar and quartz, but in some cases calcite, zeolites, etc.

2. Dark grains
Common ones are hornblende, pyroxene, garnet, ore grains, etc.

3. Mica flakes
Mostly isolated flakes of muscovite and biotite.

A high content of mica in the sand fraction results in much water being needed in the concrete and reduces the suitability of the material as aggregate. The content of sulphides and carbonate is listed separately. A special watch is kept for grains with a surface coating.

Humus and sediment determination

The humus content is determined by the soda lye method in accordance with Norwegian Standard 427, part 2.

A certain amount of sample material finer than 4 mm is shaken in a soda lye solution with a specific concentration. After a time, the fluid column may become coloured above the material that settles and this is evaluated visually on the basis of a prepared scale. The height of the sediment is also recorded.

The method may be considered as indicative. Trial casting must be performed to be certain whether possible humic acids are detrimental for concrete. The test only shows that the sample contains humic acids, not whether they have a detrimental effect on concrete.

Trial casting

Trial casting is essential when a reliable assessment is required of the suitability of the aggregate for mortar and concrete.

Mortar trial
The sand fraction (0-4 mm) is vital for the properties of concrete. Mortar casting is a convenient way of describing and classifying the quality of the fine-grained fraction of the aggregate.

The method provides an opportunity for setting specific quality demands for the fine-grained aggregate. It is particularly valuable when selecting among several potential aggregates. Only small samples are required and the method is relatively simple to carry out in the laboratory.

A given number of individual samples are cast and shaped using a standardised procedure. The method is based on the water:cement ratio and the ratio between the volumes of cement and aggregate being held constant. It is therefore the properties of the aggregate which

influence the result. Corrections for variations in maturing density are applied to samples in one and the same sample series.

The water requirement index is determined to assess the plastic properties of the mortar. Constant amounts of aggregate and cement are mixed with a quantity of water that is adequate to achieve suitable workability, as determined by a fallcone test.

The water requirement index is first and foremost dependent on the grading of the sample. The mineralogy and grain shapes of the aggregate, as well as the surface roughness of grains within it, and possible coatings on their surface, also have some effect.

Concrete trial
Trial casting of concrete is carried out when follow-up investigations of aggregates are undertaken, or when better documentation is required.

Experience has proved that the various components in a specimen of concrete cannot be fully evaluated independently of one another.

Too much importance can therefore not be attached to the compactness of the mortar when concrete is being evaluated. The correct composition and proportions of fine and coarse aggregates may even out differences in the quality of the mortar. An example of this is 'jump graded' material, which first appears to advantage during a concrete casting trial.

Trial casting of concrete is somewhat more awkward to carry out than mortar casting. Larger quantities of sample material and better laboratory equipment are needed. Because several factors influence the results, it is more difficult to assess individual results against one another.

During trial casting, it is usual to employ a constant water:cement ratio and a given amount of cement. To test ordinary construction concrete, six 10 cm cubes are cast and are then pressure tested for 1, 7 and 28 days. In addition to the breaking strength, the workability/castability, space density and content of air-filled pores are measured.

Road building purposes

The requirements for crushed stone (made from crushed rock / aggregate) vary depending upon which course in the road structure the material will be used in. The road structure may be divided into five parts: filter course, sub-base, roadbase, base-course and surface course. The last two comprise the road surface itself. Crushed stone is an important component of the sub-base, roadbase and surface courses.

Stone of stone category 4 or better is required in the upper part of the sub-base, whereas its lower part requires category 5 or better. The flakiness value of material > 11.2 mm must be < 1.70. The abrasion value must be < 0.75.

The demands for the roadbase vary depending on the type of roadbase. The choice of roadbase depends on the average annual daily traffic load (ADT). Table 1 shows the requirements of the various types of roadbase course.

TYPE OF ROADBASE		ADT				
			300	1500	5000	15000
Crushed rock Cr	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.55	3 1.55 (0.65)	3 1.55 (0.65)		
Compacted aggreg. Ca	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.60	3 1.60 (0.65)	3 1.60 0.65	3 1.60 0.65	
Compaction aggreg. Cag	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.50	3 1.50 (0.65)	3 1.50 0.65	3 1.50 0.65	
Asphalt-mixed aggreg. Aa	Stone category Flakiness value > 11.2 mm Abrasion value			4 1.60 (0.65)	3 1.55 0.65	3 1.55 0.65
Penetrated aggreg. Pa	Stone category Flakiness value > 11.2 mm Abrasion value		5 1.60 (0.75)	5 1.60 0.75	5 1.60 0.75	4 1.60 0.75
Cold aggreg. Coa	Stone category Flakiness value > 11.2 mm Abrasion value	4 1.60	4 1.60	3 1.55 (0.65)	3 1.55 0.65	
Cement-stabilised aggreg. Csa	Stone category Flakiness value > 11.2 mm Abrasion value			(5) 1.50	(5) 1.50	5 1.50

Shaded cells signify "not a usual area of use". ( ) = desirable abrasion values

Table 1
Requirements for maximum values for stone category and flakiness of material > 11.2 mm and for the abrasions value for material for a roadbase of crushed stone.

Three types of road surface can be distinguished: asphalt, gravel and concrete. Crushed rock is normally used in all three types of surface. The requirements for road surfaces are given in Table 2 a-c.

ASPHALT SURFACE		ADT					
			300	1500	3000	5000	15000
Cast asphalt, Ca	Stone category					2	1
	Flakiness value > 11.2 mm					1.45	1.45
	Abrasion value					0.45	0.40
	Resistance to wear					2.5*	2.0
	Ball mill value					9.0	6.0
Topeka, Top	Stone category					2	1
	Flakiness value > 11.2 mm					1.45	1.45
	Abrasion value					0.45	0.40
	Resistance to wear					2.5*	2.0
	Ball mill value					9.0	6.0
Skeleton asphalt, Ska	Stone category				2	2	1
	Flakiness value > 11.2 mm				1.45	1.45	1.45
	Abrasion value				0.55	0.45	0.40
	Resistance to wear				3.0	2.5*	2.0
	Ball mill value				11.0	9.0	6.0
Asphalt concrete, Ac	Stone category			3	3	2	1
	Flakiness value > 11.2 mm			1.45	1.45	1.45	1.45
	Abrasion value			0.55	0.55	0.45	0.40
	Resistance to wear			3.5	3.0	2.5*	2.0
	Ball mill value			13.0	11.0	9.0	6.0
Drain asphalt, Da	Stone category			3	2	2	
	Flakiness value > 11.2 mm			1.45	1.45	1.45	
	Abrasion value			0.55	0.55	0.45	
	Resistance to wear			3.5	3.0	2.5*	
	Ball mill value			13.0	11.0	9.0	
Asphalt gravel concrete, Agc	Stone category	3	3	3			
	Flakiness value > 11.2 mm	1.50	1.50	1.50			
	Abrasion value		(0.65)	0.55			
	Resistance to wear			3.5			
	Ball mill value			13.0			
Soft asphalt, Sa Soft drain asphalt, Sda	Stone category	3	3	3			
	Flakiness value > 11.2 mm	1.50	1.50	1.45			
	Abrasion value		(0.65)	(0.55)			
	Resistance to wear			3.5			
	Ball mill value			13.0			
Cold gravel, Cg, Cd	Stone category	3	3	3			
	Flakiness value > 11.2 mm	1.50	1.45	1.45			
	Abrasion value		(0.65)	0.55			
	Resistance to wear			3.5			
	Ball mill value			13.0			
Surface treatment, St DSt	Stone category	3	3	3			
	Flakiness value > 11.2 mm	1.50	1.45	1.45			
	Abrasion value		(0.55)	0.50			
	Resistance to wear			3.5			
	Ball mill value			13.0			
Surface treatment with gravel, Stg, DStg	Stone category	3	3				
	Flakiness value > 11.2 mm	1.50	1.45				
	Abrasion value						
Oil gravel, Og	Stone category	3	3				
	Flakiness value > 11.2 mm	1.50	1.45				
	Abrasion value						
Asphalt scum gravel, Asg	Stone category	3	3				
	Flakiness value > 11.2 mm	1.50	1.50				
	Abrasion value						

Shaded cells signify "not a usual area of use". ( ) = desirable abrasion values

* Stricter demands should be considered for ADT > 10,000

Table 2a
Requirements for maximum values for stone category, flakiness of material > 11.2 mm, abrasion value, resistance to wear and ball mill value for aggregates for asphalt surfaces.

GRAVEL SURFACES		ADT: 300	1500	3000	5000	15000	
Gravel	Stone category Flakiness value > 11.2 mm	3 1.50					

Shaded cells signify "not a usual area of use".

Table 2b
Requirements for maximum values for stone category and flakiness of material > 11.2 mm for aggregates for gravel surfaces.

CONCRETE SURFACES		ADT: 300	1500	3000	5000	15000	
Concrete, C70 - C90	Stone category Flakiness value > 11.2 mm Abrasion value					2 1.45 0.45	1 1.45 0.40
Concrete, C40 - C70	Stone category Flakiness value > 11.2 mm Abrasion value				3 1.45 0.55	2 1.45 0.45	2 1.45 0.40
Rolled concrete, C35 - C55	Stone category Flakiness value > 11.2 mm Abrasion value		3 1.45 (0.65)	3 1.45 0.55	3 1.45 0.55		

Shaded cells signify "not a usual area of use". ( ) = desirable abrasion values

Table 2c
Requirements for maximum values for stone category, flakiness of material > 11.2 mm and abrasion value for aggregates for concrete surfaces.

With a few exceptions, Table 2a, requirements for asphalt surfaces, may be simplified as shown in Table 3.

Property	Annual daily traffic (ADT)					
Stone category	1 - 3			1 - 2		1
Abrasion value	-	(≤0.65)	≤ 0.55		≤ 0.45	≤ 0.40
Resistance to wear	-		≤ 3.5	≤ 3.0	≤ 2.5*	≤ 2.0
Ball mill value	-		≤ 13.0	≤ 11.0	≤ 9.0	≤ 6.0

Figure in brackets indicates the desired value.

* Stricter demands should be considered for ADT > 10,000

Table 3
Requirements for stone category, abrasion value, resistance to wear and ball mill value for surface aggregates. **Exceptions in the table** concern asphalt concrete, which accepts up to stone category 3 for ADT < 5000 and surface treatments where the requirements for the abrasion value are £ 0.50 for ADT 1500-3000 and (£ 0.55) for ADT 300-1500.

Concrete purposes

Apart from the flakiness value, no specific demands have been stipulated for the mechanical properties of crushed aggregates for concrete. The flakiness value should be less than 1.45 for the 11.2-16.0 mm fraction. Experience has shown that flakiness depends more upon the crushing equipment and the crushing process than the mineral content and the texture of the rock.

In general, rocks intended for use for concrete should be "mechanically good" and contain as little mica as possible (the kind of mica is decisive, but preferably < 10%). An excessive content of certain sulphides (iron pyrites, pyrrhotite) is undesirable.

Manufacture of high tensile concrete calls for such high compactness that the aggregate constitutes the weak link. The demand on the mechanical properties is therefore greater, but no detailed quality criteria are available.

Silicic acid in quartz crystals, capable of dissolving alkalis, may react with the cement paste and result in concrete fracturing and expanding in volume. In recent years, a number of concrete constructions in Norway have been found to have been damaged by alkaline reactions (AR). The chemical reaction is extremely slow and only takes place under unfavourable conditions with high moisture and temperature stress, such as on bridges and dams. The damage is often not discovered before 15 to 20 years elapse. The detrimental reactions may be linked with the following potentially alkali-reactive rock types:

* Sandstone/greywacke/siltstone
* Mylonite/cataclasite
* Rhyolite/acid volcanic rocks
* Argillite/phyllite
* Quartzite (microcrystalline and fine grained)

In addition, the following are classified as possibly alkali reactive:

* Quartzite (fine grained/quartz schist)
* Fine-grained quartz-rich rocks
* Limestone with pelitic texture

This list of detrimental rocks is not final. New research continually leads to revisions.

Road building purposes

The following requirements apply in England:

Road construction		Testing method	Traffic load (cv/lane/day) 1500 6000		
Non-bonded		LA ACV AIV 10% fines	< 35 < 30 < 30 > 100	< 30 < 27 < 27 > 115	< 25 < 23 < 23 > 130
Asphalt bonded	Surface dressing, pervious macadam	LA ACV AIV 10% fines	< 25 < 23 < 23 > 130		< 16 < 16 < 16 -
	Dense wearing course	LA ACV AIV 10% fines	< 30 < 27 < 27 > 115		< 25 < 23 < 23 > 130
	Roadbase and sub-base	LA ACV AIV 10% fines	< 35 < 30 < 30 > 100		
Cement bonded	Cement surface	LA ACV AIV 10% fines	< 35 < 30 < 30 > 100		< 30 < 27 < 27 > 115
	Roadbase and sub-base	LA ACV AIV 10% fines	< 35 < 35 < 35 > 50		

Table 1.
Critical limiting values for some mechanical testing methods relative to the traffic load (cv/lane/day) and type of road construction

LA - Los Angeles, ACV - aggregate crushing value,
AIV - aggregate impact value, 10% fines - dry state.

Road surface	Traffic load (cv/lane/day) 250 1000 1750 2500 3250 4000		
Chippings	< 14	< 12	< 10
Wearing courses	< 16	< 14	< 12

Table 2.
Critical limiting values for aggregate abrasion value (AAV) relative to the traffic load (cv/lane/day) and road surface.

<table>
<tr><th>Road category</th><th>Proportion road length in England</th><th colspan="7">Traffic load
(cv/lane/day)
250 1000 1750 2500 3250 4000</th></tr>
<tr><td>A1</td><td>< 0.1%</td><td>> 60</td><td>> 65</td><td>> 70</td><td colspan="4">> 75</td></tr>
<tr><td>A2</td><td>< 4%</td><td colspan="3">>60</td><td>> 65</td><td>> 70</td><td colspan="2">> 75</td></tr>
<tr><td>B</td><td>< 15%</td><td colspan="3">> 55</td><td colspan="3">> 60</td><td>> 65</td></tr>
<tr><td>C</td><td>< 81%</td><td colspan="7">> 45</td></tr>
</table>

Table 3.
Critical limiting values for the polished stone value (PSV) relative to the traffic load (cv/lane/day) and road category:

A1 - At traffic lights, pedestrian crossings and on dangerous stretches of road in built-up areas
A2 - At major crossroads, roundabouts, sharp bends and on steep inclines
B - Motorways, main roads, other roads with traffic loads > 250
C - Roads with light traffic loads (cv/lane/day < 250) and roads without risk of frictional accidents.

The following requirements apply in Germany:

	Number of vehicles weighing > 5 tonnes				
	>3000	3000-1500	1500-500	500-100	<100
Road category	I	II	III	IV	V
Asphalt road surfaces	18 (20)	18 (20)	18 (20)	22 (25)	26 (30)
Bonding course	18 (20)	18 (20)	22 (25)	26 (30)	26 (30)
Special uses	15 (15)	15 (15)	15 (15)	-	-

Table 4.
Limiting values for the Schlagversuch value (Los Angeles value) relative to the traffic load, road category and area of use. The Los Angeles values are not real, but have been calculated on the basis of the ratios between the two methods as they appear in Table 5.

The Schlagversuch values, the Los Angeles values and the Swedish impact test have been correlated (Høbeda 1981). On this basis and the categories valid for Europe, it is possible to prepare the following correlation table showing the limiting values for these methods:

Category (LA)	Los Angeles (LA)	Brittleness value	Schlagversuch (SL)	Category
A	≤ 15	≤ 40	≤ 15	-
B	≤ 20	≤ 45	≤ 18	A/B
C	≤ 25	≤ 50	≤ 22	C
D	≤ 30	≤ 60	≤ 26	D/E
E	≤ 40	-	≤ 32	F
F	≤ 50	-	-	

Table 5.

	Number of vehicles weighing > 5 tonnes				
	>3000	3000-1500	1500-500	500-100	<100
Road category	I	II	III	IV	V
Asphalt road surfaces	> 50			> 43	
Special uses	> 55				

Table 6.
Proposal for limiting values for PSV relative to traffic load, road category and area of use

Rock type	Granite Syenite	Diorite Gabbro	Quartz porphyry Keratophyre Porphyrite Andesite	Basalt Dolerite	Limestone Dolomite	Greywacke Quartzite Vein quartz Quartz sandstone	Gneiss Granulite Amphibolite
Schlagversuch value	10 - 22	8 - 18	9 - 22	7 - 17	16 - 30	10 - 22	10 - 22

Table 7.
Permitted Schlagversuch values for roadbase material for some rock types.
Values vary between 7 and 30.

The following requirements apply in France:

<table>
<tr><th rowspan="2">ROADBASE AND SUB-BASE COURSES</th><th rowspan="2">TESTING METHOD</th><th colspan="8">Number of vehicles weighing > 5 tonnes</th></tr>
<tr><th colspan="8">75 100 150 300 500 600 1000</th></tr>
<tr><td>Asphalt gravel</td><td>Los Angeles</td><td colspan="3">< 30</td><td colspan="5">< 25</td></tr>
<tr><td>Cement-stabilised gravel</td><td>Los Angeles</td><td colspan="2">< 35</td><td colspan="5">< 30</td><td></td></tr>
<tr><td>Roadbase gravel</td><td>Los Angeles</td><td>≤ 30</td><td colspan="2">≤ 25</td><td>≤ 20</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 8
Requirements for roadbase and sub-base courses courses for various traffic loads.

<table>
<tr><th rowspan="2">WEARING SURFACE</th><th rowspan="2">TESTING METHOD</th><th colspan="7">Number of vehicles weighing > 5 tonnes</th></tr>
<tr><th colspan="7">75 100 150 300 500 600 1000</th></tr>
<tr><td rowspan="2">Surface treated</td><td>Los Angeles</td><td>-</td><td>< 25</td><td>< 20</td><td colspan="3">< 15</td><td>-</td></tr>
<tr><td>PSV</td><td>> 40</td><td>> 40</td><td>> 40</td><td colspan="3">> 45</td><td>> 45</td></tr>
<tr><td rowspan="2">Asphalt concrete</td><td>Los Angeles</td><td colspan="6">< 20</td><td>< 15</td></tr>
<tr><td>PSV</td><td colspan="6">> 50</td><td>> 50</td></tr>
<tr><td>Asphalt gravel</td><td>Los Angeles</td><td colspan="5">< 30</td><td colspan="2">< 25</td></tr>
<tr><td>Cement-stabilised gravel</td><td>Los Angeles</td><td colspan="4">< 35</td><td colspan="3">< 30</td></tr>
<tr><td>Roadbase gravel</td><td>Los Angeles</td><td>≤ 30</td><td colspan="2">≤ 25</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 9.
Requirements for the wearing surface for various traffic loads

The following requirements apply in the Netherlands:

Road category	1 - 2	3	4 (Motorway)
PSV	≥ 48	≥ 53 (50)	≥ 65

Table 10.
Limiting values for PSV depending on road type.

The following requirement applies in Belgium: PSV > 50

For concrete:

The requirements placed on aggregates for concrete, including concrete for road building purposes, exist as proposals for European norms in prEN 12620:1996. If necessary, stipulations may be placed on a number of physical and mechanical properties. Only the stipulations for two properties will be cited here.

Grain shape for coarse aggregate

The flakiness index for aggregate > 4 mm, determined in accordance with prEN 933-3, is divided into the following categories, depending on what is necessary:

Flakiness index	Category
≤ 20	FIA
≤ 35	FIB
≤ 50	FIC
No demands	FID

FIA - Not normally required for concrete

FIB - Normally required for crushed stone and gravel, slag and artificial aggregates

FIC - Normally required for non-crushed sand and gravel

FID - Applies in cases where it has been shown that satisfactory concrete can be manufactured.

Los Angeles:

When necessary, demands may be placed on the Los Angeles value, which must be determined in accordance with prEN 1092-2. The following category divisions apply:

Los Angeles value	Category
≤ 20	LAA
≤ 30	LAB
≤ 40	LAC
>40	LAD

LAA - Normally only required in special cases, such as where studded tyres are used.

LAB - May be required for wearing surfaces and deck constructions exposed to high loads

LAD - Applies in cases where it has been shown that satisfactory concrete can be manufactured