

Subject: Tests on the load bearing capacity of shoulders

Objective:

The purpose of this study is to test several pavement shoulder structures in order to assess the requirement that New Large Aircraft (NLA) would demand.

International Civil Aviation Organization identifies three potential functions for shoulders :

- To support airplane without inducing structural damage to it;
- To support load of ground vehicles;
- To resist erosion and prevent ingestion of surface materials by aircraft engines.

The two first functions have an impact on bearing capacity; so, structure of shoulders could be designed in correlation with subgrade and load of aircraft considering at least one pass.

Introduction of New Large Aircraft with individual wheel load exceeding 25 t led Airbus and the STAC (French civil aviation technical center) to perform a full-scale test experiment for comparing various shoulder structures.

An experimental shoulder with five different structures was tested with a NLA Wing Landing Gear module (B747 wheel arrangement combined with A380 Wing-Landing-Gear individual wheel load).

This paper describes the experiment context, site selection, test section construction, test procedures and results.

This experiment showed one of tested structures was able to support at least one pass of NLA gear. Then, this shoulder section was tested with the load applied during 18 hours. No permanent deformation was observed.

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TESTS ON THE LOAD BEARING CAPACITY OF SHOULDERS



Study report



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1) Introduction

Background

A requirement for new tests on the load bearing capacity of shoulders has evolved for the observations about Runway Design Methods and about the A380 Development. The A380 has been designed for operations from a 45-m wide runway. As it will be the largest aeroplane to use 45m runways, attention has been focussed on the importance of runway shoulders and their role in safe aircraft and airport operations.

The excursion of an aircraft off the runway onto the shoulder is not however specific to the A380. It is a safety provision for all aircraft, similar to the gradient requirements of the runway strip. The strength and width of runway shoulders must, however be practically related to the type of aircraft capable of using the runway for which the shoulder is provided. Details of shoulder design criteria are provided below.

Purpose of taxiway and runway shoulders

The ITAC and the ICAO Annex 14 identifies three potential functions for shoulders¹ in various paragraphs (see differences identified between § in ITAC and ICAO, appended), they are to:

1. Support the aeroplane without inducing structural damage to the aeroplane.
2. Support the weight of ground vehicles.
3. Resist erosion and prevent the ingestion of surface materials by aircraft engines.

The first two functions have a clear impact on the load bearing capacity required for the shoulder structure, whereas the third function relates to the properties of cohesion and resistance to blast of the shoulder surface.

To meet these requirements, it is appropriate to separate the runway shoulder design requirements from those of the taxiway shoulder. This is because the risks associated with the landing and take off phases are considerably more critical than those associated with the taxi phase: the damage to an aircraft departing a taxiway is of significantly lower risk than the damage that would be caused to an aircraft at high speed by a shoulder load bearing failure.

The current opinion (in particular as espoused by the AACG), is that:

- The functions of ground vehicle access and blast protection should be satisfied for both the runway and taxiway shoulders: the technical solutions to solve the problems may vary according to local conditions (ground cohesion) and blast protection for taxiway shoulders may differ from one zone to another²
- The occasional load bearing capacity function should be satisfied for runway shoulders only: the shoulder in fact plays a central role of providing a transition between the runway pavement and the built-up strip.

In theory, the choice of this type of definition for runway shoulders leads to their construction according to the nature of the ground base, to allow for at least one overrun by the critical aircraft without it incurring any structural damage..

¹ The terms used here are from annex 14

² Intersections, curves, zones at stopping points and turnpad may need a specially enhanced treatment against blast.

In practice, this type of design requirement cannot be practically evaluated. This case exceeds the pavement design for which current methods are valid. Furthermore, there is no analytical calculation model available to calculate the rut depth caused by a single overrun by the critical aircraft.

2) Planned Tests

Upon evaluation it was decided that as there were no reliable theoretical models available, and therefore full size testing was required.

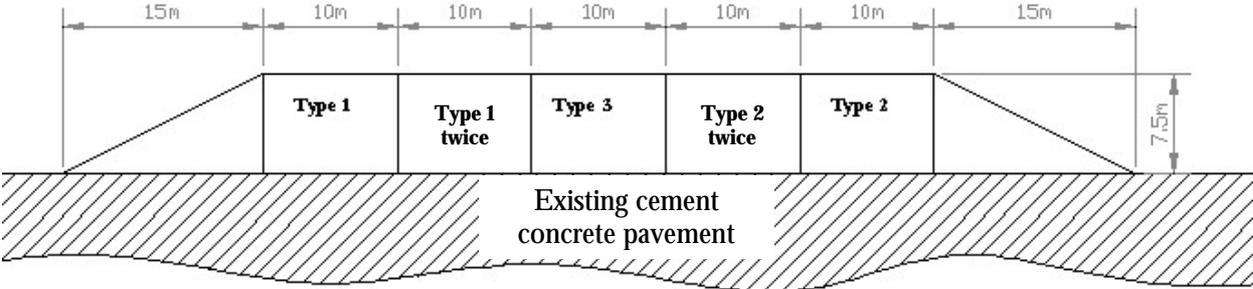
Selected site

The search for a site at Toulouse Blagnac was carried out locally by the SLBA and Airbus France led to choosing a location in the Airbus France zone, outside the airport aeronautical facilities. This is a recently built cement concrete taxiway. Test sections were consequently built as a shoulder to this taxiway.

Test Section Construction

The shoulder structures tested during these tests were derived from the minimum structure requirements of the ITAC (type 2 twice structure), and the structures used by ADP (type 1 structure) with an experimental structure added (Type 3).

The final version of the test sections were then constructed as follows:



Plan view

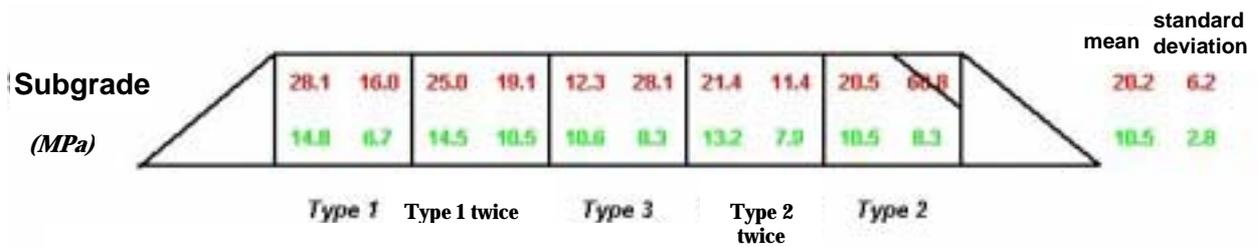
Type 1 (ADP , Toulouse)	Type 1 twice	Type 3	Type 2 twice	Type 2
- 6 cm of BBA - 20 cm of GLSR - 30 cm of subgrade treated with 2% quicklime	- 6 cm of BBA - 20 cm of GLSR - geotextile fabric - natural subgrade	- 6 cm of BBME - 20 cm of GRH - geotextile fabric - natural subgrade	- 6 cm of BBA - 20 cm of GRH - geotextile fabric - natural subgrade	- 6 cm of BBA - 20 cm of GRH - 30 cm of subgrade treated with 2% quicklime

BBA: aeronautical bituminous concrete (0/10 class 2)
 BBME: high modulus bituminous concrete (0/10)
 GLSR: Special Roadway Hydraulic binder aggregate (0/14)
 GRH: humidified reconstituted aggregate (0/20)

The transversal slope adopted for all sections was 1.5%.

Preliminary Tests and Results

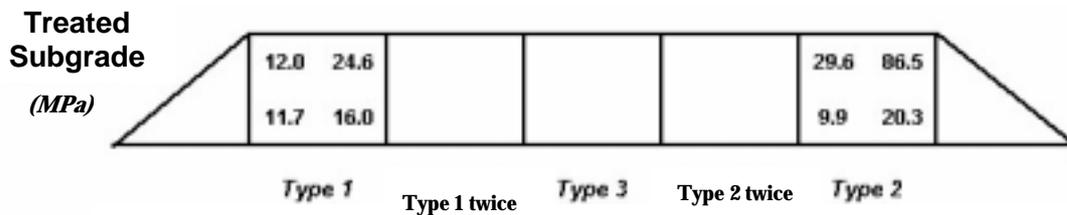
Bearing strength tests (EV2 modulus tests) were carried out on the natural subgrade, the soil after treatment and the base course during the construction of the test structure:



The practical results obtained on the test surfaces showed a much lower load bearing capacity than expected from calculations of the surface design, which had targets of CBR³ 7 and 10. In fact, an average 15.1 MPa value was obtained, corresponding more closely to a 2 or 3 CBR value.

Moreover, the sample is relatively dispersed (standard deviation around 7 MPa). The results showed two distinct area of strength, represented in red and in green on the diagram above which had much less scatter results. The zone corresponding to the green line was effectively excavated more than the other during the construction works (recent) of the adjacent concrete runway (slip form passage, etc.).

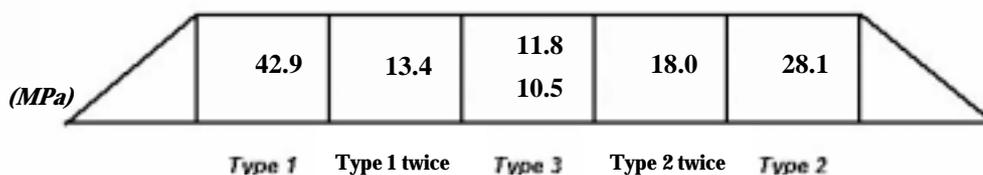
Despite these very low values it was decided nevertheless to retain the planned structure for the remainder of the tests. However it was recognized that some test sections (especially type 2 twice) would have obvious structural weaknesses.



The treatment process was as follows: the soil was first of all extracted, treated then put back in place and compacted. This explains the load bearing capacity drop after treatment (comparison between points 10.7 not treated and 9.9 treated). Moreover, the measurements indicated above are very short-term measurements (D+1). However, the load bearing capacity of treated subgrade increases significantly in the long term.

Bearing strength measurements (EV2 Module) made following the tests in a probe gave the following results (probe test were made in the middle of the plates on a middle line between the red and green lines, except for type 3 section for which two tests were made):

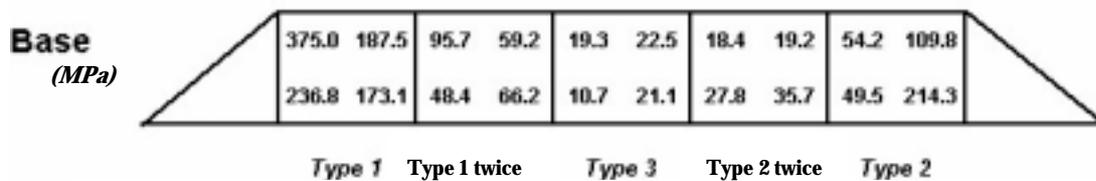
Medium term soil load bearing capacity



It was found that the non-treated subgrade load bearing capacity did not change significantly (i.e. was within experimental scatter). On the contrary the load bearing capacity of treated subgrade considerably increased (taking into account the location of probe test, the 28.1 MPa value obtained on type 2 section is to be compared with the 9.9 and 20.3 MPa values obtained immediately after treatment).

Therefore a CBR value was assessed as 3 for natural subgrade and a CBR value was assessed as 6 for treated subgrade.

³ Californian Bearing Ratio.



Measurements above reveal a relatively wide dispersion of values for GLSR base courses (Type 1 and Type 1 twice), as well as for the GRH base course on treated subgrade (Type 2). On the other hand, results are more homogeneous on the GRH base course on untreated subgrade (Type 2 twice and Type 3). Also, a zone weaker than the others (10.7 MPa) is found.

The following ranking of the pavement bearing strengths was expected to be confirmed during tests with the landing gear:

$$\text{Type 1} > \text{Type 1 twice} \approx \text{Type 2} > \text{Type 2 twice} = \text{Type 3}$$

3) Further tests and measurements made

Principle goals

The purpose of these tests was to verify whether the shoulder types scheduled were capable of supporting the occasional overrun by a bogie of the design case heavy aircraft. In fact, the interest was more the possible damage to the aircraft that a pavement deforming or failing under a single overrun could cause to a bogie, rather than the converse damage to the pavement.

Therefore, the first goal was to observe the failure mode after a single overrun of the test sections. The fact that the low velocity test conditions were much more penalizing for the pavement than the "operational" overrun conditions had an effect on the interpretation of test results.

- **Thus, the test section has been considered suitable for occasional passage if the bogie did not cause serious damage (specifically piercing of the surface or of the rut) and most importantly, during the passage of the aircraft.** In fact, a different level of the final deformation of the structure could be accepted. That is, the bogie would run over without significant immediate damage to the section (and consequently no damage to the bogie). Structural damage could then occur later (e.g. the following day). This was not considered limiting as in the event of an aircraft leaving the runway, the shoulder would be inspected and /or repaired before use by further limiting case airplanes. If a section passed the adverse test conditions, it was considered suitable for operational purposes.

- If on the other hand the section incurred significant damage during the tests, it would not be possible to conclude that the particular section did not meet the operational conditions. The extent of the damage would however give an indication of the operational suitability.

Critical load

The selected critical aircraft was the A380, as the available A380 PEP⁴ rigid test modules, made it possible to easily simulate this aircraft. Only the 4-wheel wing bogie was taken into account (as it is the outboard one and therefore the most likely to run on the shoulder).

⁴ A380 Pavement Experimental Programme has been launched by LCPC, STBA, Airbus in 1998.

A 4-wheel module was constructed corresponding to the size of the A380-800 landing gear (track 135 cm and base 170 cm) and was towed by a truck provided by the STBA that had also been used for the PEP. Initially, the selected wheel load was that of the A380-800 (MTOW 560T), which was 26.7 T/wheel. During a second phase the wheel load was increased to 28.6T/wheel (corresponding to the A380-800F, at a MTOW 600T). A 2-wheel module (track 140 cm) with a 21.5 T/wheel load was also used, this was because the 4-wheel module was only able to roll in a straight line when towed by the truck, as there was a problem with tow bar resistance when turning. A crane was permanently located on the site during trials to pick up and load the module on the junction strips.



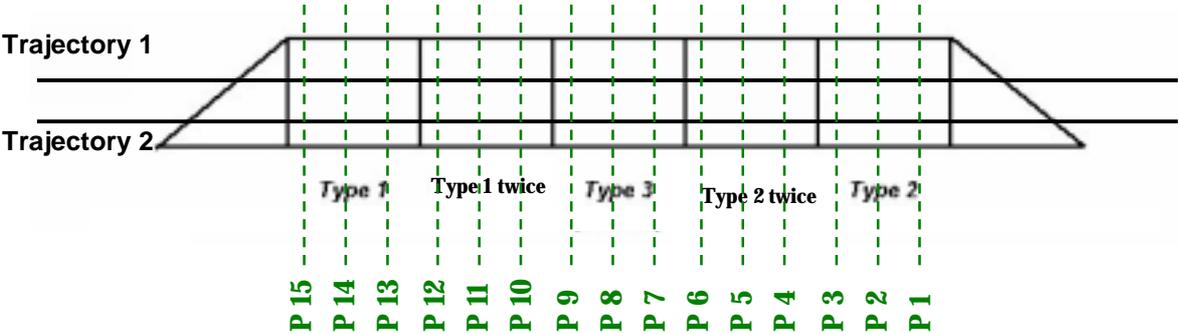
▲ *Picture no. 1: Picking up and loading the 4-wheel module.*

The rolling speed of around 3 km/h, simulated the worst case condition of passage over the shoulder as in practice the rolling speed would be much higher and the time to inflict damage, less.

Test procedure

Tests took place on the 3rd and 4th of July 2002.

The trajectory co-ordinates as well as the profile of the rut depth were recorded every 2.5m (see below). The profile of the rut depth was also recorded the next day. Several tests were done with two passages on the surface, and one static test was performed on the type 1 surface.



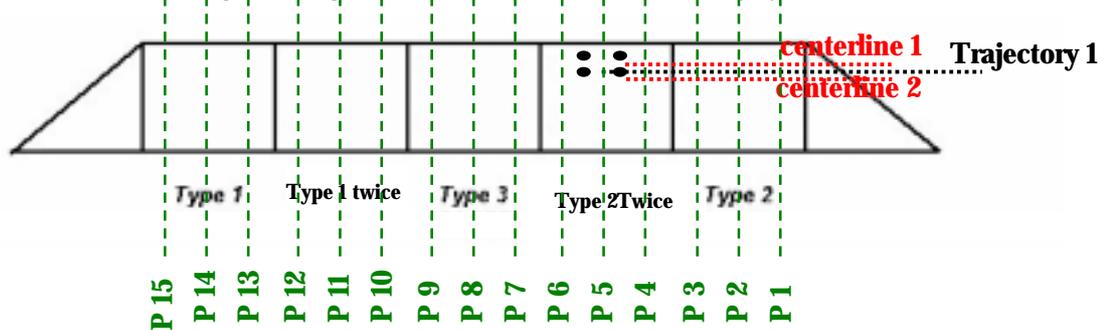
Results

In summary there were two kinds of behavior. If the bearing capacity of the shoulder was adequate, the bogie was able to run onto the shoulder several times with or without elastic deformation. Alternatively if the bogie sank (either suddenly or not) it was then necessary to use the crane to extract the module and return it to the Concrete Cement taxiway.

Details were:

Test 1: 4-wheel module: A380-800 trajectory 1 (type 2 to type 1)

The beginning of test was on 03/07/02 at 9:05 am local time, test stopped at 9:06 am. The bogie sank on the type 2 twice structure. Bogie sinking was sudden and remained relatively symmetrical.



Several records of the rut were made: immediately after the test, on the same day at 3:15 pm local time and the next day (04/07/02) at 7:30 am local time

		Centerline 1			Centerline 2		
		03/07/02 at 9:06 am	03/07/02 at 3:15 pm	04/07/02 at 07:30 am	03/07/02 at 9:06 am	03/07/02 at 3:15 pm	04/07/02 at 07:30 am
		Type 2	P1	3 mm	2 mm	2 mm	3 mm
P2	14 mm	13 mm	13 mm	13 mm	13 mm	13 mm	
P3	10 mm	7 mm	9 mm	8 mm	8 mm	7 mm	
Type 2 twice	P4	30 mm	30 mm	30 mm	30 mm	29 mm	28 mm
Maximum rut, rear axle	70 mm			70 mm			
P5	55 mm	46 mm	48 mm	62 mm	48 mm	48 mm	
Maximum rut, front axle	145 mm			139 mm			
P6	Not used			Not used			

Taking into account the rut results recorded immediately after rolling the conclusions with regard to occasional rolling on these shoulders for the A380-800 4-wheel bogie are as follows:

- type 2 section: acceptable for experimental conditions and therefore suitable for operational conditions (with a definite requirement to plan repair works of the shoulder following runway excursion and/or immobilization of a heavy aircraft on the shoulder).

- type 2 twice section: unsuitable under experimental conditions. It is not possible to draw conclusions for operational conditions.

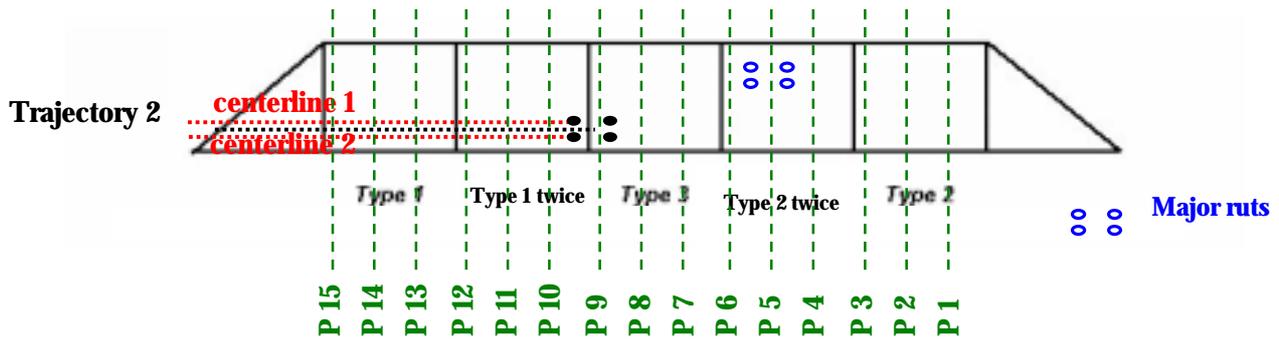
Remark in this case the very significant influence of the treated subgrade.

Moreover, no further increase to the rut depth over time. In fact, the rut depth was minimal.

Test 2: 4-wheel module: A380-800 trajectory 2 (type 1 to type 2)

The beginning of test was on 03/07/02 at 11:25 am local time, test stopped at 11:26 am (bogie sinking on the type 3 structure).

Sinking of the bogie was very sudden and was highly asymmetrical, which suggested there was a lateral variation in the subgrade strength under the two bogies tyre center lines of subgrade contact.

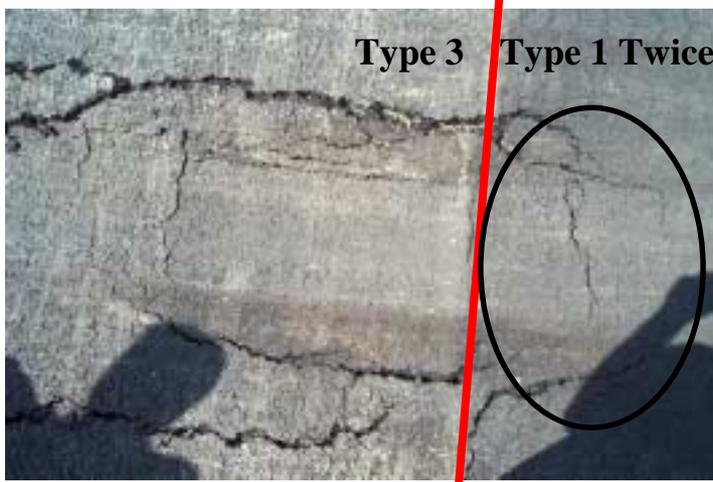


Several records of the rut were made: immediately after the test, on the same day at 3:15 pm local time and the next day (04/07/02) at 7:30 am local time

		Centerline 1			Centerline 2		
		03/07/02 at 11:26 am	03/07/02 at 3:15 pm	04/07/02 at 07:30 am	03/07/02 at 11:26 am	03/07/02 at 3:15 pm	04/07/02 at 07:30 am
Type 1	P15	≈ 1 mm	< 1 mm	NM ⁵	≈ 1 mm	< 1 mm	NM
	P14	≈ 1 mm	< 1 mm	NM	≈ 1 mm	< 1 mm	NM
	P13	≈ 1 mm	< 1 mm	NM	≈ 1 mm	< 1 mm	NM
Type 1 twice	P12	5 mm	3 mm	2 mm	3 mm	1 mm	< 1 mm
	P11	4 mm	2 mm	2 mm	2 mm	< 1 mm	< 1 mm
	P10	6 mm	12 mm	12 mm	2 mm	< 1 mm	< 1 mm

No profile was reached on the type 3 section, and therefore no recording was made.

In fact, the analysis of the load bearing capacity (refer to paragraph « Preliminary Results ») reveals that the rupture zone is precisely located on the weakest point recorded on the base (zone at 10.7 MPa, which is very weak). This typical weakness of the base subgrade even partly extends to type 1 twice section:



It was found that the subgrade type 3 induced damage to the GLSR course causing rupture of surface material in section type 1 twice. This certainly explains the different observations made for the type 1 twice section between profiles P12 and P11 (highly comparable) and profile P10.

(rear axle)

▲ Picture no. 2: rut Type 3 section, view according to centerline 1

This rupture, due to this exceptionally weak zone in the base, made it impossible to reach a conclusion on the behavior of BBME (by comparison with the rupture in type 2 twice of test no. 1).

⁵ NM: not measurable

Taking into account the rut results recorded immediately after rolling, the conclusions with regards to occasional rolling on these shoulders for the 4-wheel bogie of the A380-800 are as follows:

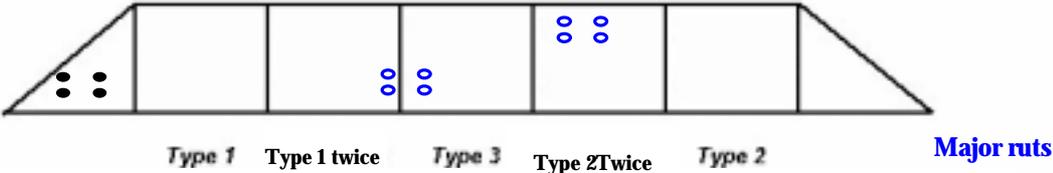
- type 1 section acceptable after the experiment and therefore suitable for operational conditions: no structural damage appeared after the bogie had rolled over it once.
- type 1 twice section: acceptable after the trial vehicle passage and therefore suitable for operational conditions. Residual damage was found afterwards that could require repair works.

It is found that type 1 twice section behaves a priori better than type 2 twice structure (rut depth less), which was not an obvious result according to the plate test (bearing strength test on subgrade c.f. Preliminary Tests and Results page 3).

Moreover, there is no increase to the rut depth over time was found. In fact a slight reduction occurred over time(except for profile P10 centerline 1, which is explained due to the base subgrade).

Test 3: 4-wheel module A380-800, immobilized on junction band

Considering the high level of resistance of the type 1 section, it was decided to place the loaded module on one of the junction bands (structure identical to type 1) and to leave it there until the next morning. The module was positioned around 3pm under a relatively high temperature (ambient temperature around 25°C and 40°C at the surface).



^ Picture no. 3: A380-800 static test on junction band

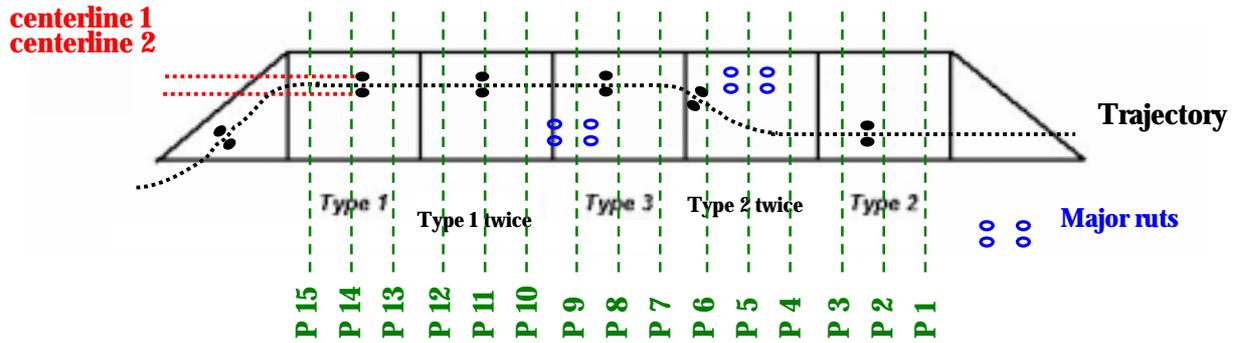
Observations made the next morning (after more than 18 hours in place) revealed slight creep of the surface material, strictly localized under the tire footprint, to a depth of around 2mm maximum, which most probably was caused by the relatively high pavement temperature at the beginning of the test.

This type 1 section therefore shows excellent resistance, and it should be possible for a large aircraft to roll over it several times without any damage.

Test 4: 2-wheel module, S trajectory (type 1 to type 2)

A 2-wheel module (track 140cm), with a lighter load (21.5 T/wheels), offered the advantage of being highly maneuverable and made it possible to follow an S trajectory so as to roll over different areas that had not previously been subject to a test vehicle passage. The goal was to cross all sections, and in particular to try to compare the behavior of type 3 and type 2 twice.

The beginning of test was on 04/07/02 at 08:25 am local time (surface material surface temperature: 22°C): trials took place on all sections.



The rut depth measurement results are :

		Centerline 1	Centerline 2
Type 1	P15	0 mm	0 mm
	P14	0 mm	0 mm
	P13	0 mm	0 mm
Type 1 twice	P12	2 mm	0 mm
	P11	2 mm	0 mm
	P10	2 mm	0 mm
Type 3	P9	7 mm	15 mm
	P8	6 mm	8 mm
	P7	12 mm	12 mm
Type 2 twice	P6	30 mm	10 mm
	P5	58 mm	18 mm
	P4	24 mm	8 mm
Type 2	P3	6 mm	NM ⁶
	P2	6 mm	NM
	P1	3 mm	NM

Therefore, relatively good shoulder resistance was found.

Even if the considerable deformation under centerline 1 for type 2 twice section is confidently explained in part by rolling relatively close to the rut created during test no. 1, it seems that type 3 section offers better resistance than type 2 twice section

However, these results do not take into account the very high elastic deformation (around one centimeter at least) during rolling of the 2-wheel module on 2 twice and 3 sections, which can even be observed under the rear axle of the truck:

⁶ NM: not measurable as at end of trajectory, the tire of centerline 2 was overlapping the test zone and the adjacent concrete taxiway.

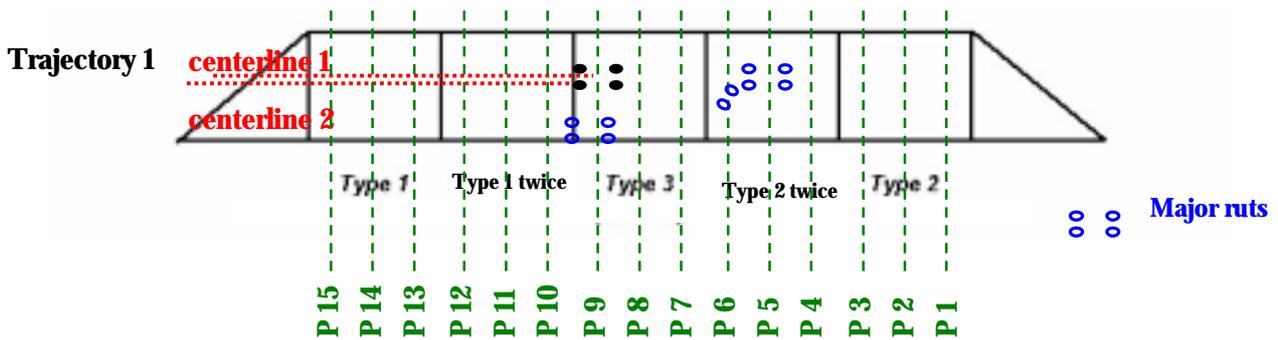


◀ *Picture no. 4: deformation type 3 section under the rear axle of the truck*

Test 5: 4-wheel module: A380-800F trajectory 1 (type 1 to type 2)

The beginning of test was on 04/07/02 at 9:30 am local time (surface material temperature: 30°C), test stopped at 9:31 am (bogie sinking on the type 3 structure)

Sinking of the bogie was not as sudden as recorded during test no. 2 on the same section: the footprint in BBME remains relatively symmetrical (comparison of centerlines 1 and 2).



As the 2-wheel module has already rolled on this trajectory the rut depths recorded after rolling are indicated for reference purposes only:

		Centerline 1		Centerline 2	
		<i>2 wheels</i>	<i>04/07/02 at 9:30 am</i>	<i>2 wheels</i>	<i>04/07/02 at 9:30 am</i>
Type 1	P15	0 mm	1.5 mm	0 mm	0 mm
	P14	0 mm	1.5 mm	0 mm	0 mm
	P13	0 mm	2 mm	0 mm	0 mm
Type 1 twice	P12	2 mm	5 mm	0 mm	4 mm
	P11	2 mm	6 mm	0 mm	4 mm
	P10	2 mm	19 mm	0 mm	5 mm

Sinking of the bogie was not as sudden as recorded during test no. 2 on the same section: the footprint in BBME remains relatively symmetrical (comparison of centerlines 1 and 2) and especially the coated material has not given away as during previous tests. In fact, it lifted up (see photo plates in appendix).

The pavement had not caved in. The truck was not powerful enough to pull out the module from the rut (the test could have been continued if a more powerful truck had been available). The behavior of type 3 section during this test seems to show the capability of BBME to prevent abrupt rupture of the pavement. However, taking into account the weakness of the base at this part of the section (point at 19 MPa on the base course, most certainly explaining partly the deformation of profile P10) it does not enable us to conclude on the occasional rolling capacity of type 3 section.

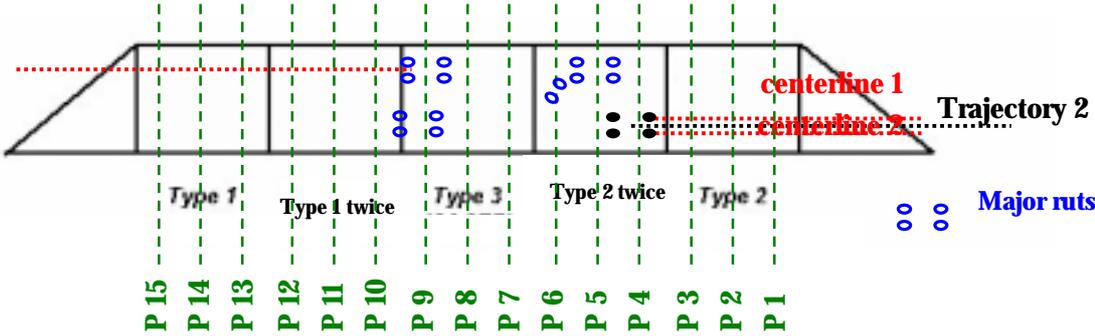
Taking into account the rut results recorded immediately after rolling, the conclusions with regards to occasional rolling on these shoulders for the 4-wheel bogie of the A380-800F are as follows:

- type 1 section acceptable after the experiment and therefore suitable for operational conditions normally less damaging: no structural damage appears after the bogie has rolled over it once.
- type 1 twice section: acceptable after the trial vehicle passage and therefore suitable for operational conditions normally less damaging. Residual damage was found afterwards that could require repair works.

Test 6: 4-wheel module; A380-800F trajectory 2 (type 2 to type 1)

Beginning of rolling on 04/07/02 at 11:00 am local time (surface material temperature: 30°C), test stopped at 11:01 am (bogie sinking on the type 2 twice structure)

The bogie suddenly sank with a steep depression of tyre 1 centerline while tyre 2 remained at the test surface level. Sinking was entirely asymmetrical (practically no deformation under centerline 2), which may be due to a weakness in the center zone of the base.



As the 2-wheel module has already rolled on this trajectory the rut depths recorded after rolling are indicated for reference purposes only:

Moreover, setting up of this test made it necessary to roll the module unloaded (40tons, i.e. 10t/wheel). Therefore, deformation before the test was consequently recorded:

		Centerline 1			Centerline 2		
		2 wheels	04/07/02 at 10:50 am	04/07/02 à 10:50 am	2 wheels	04/07/02 at 9:30 am	04/07/02 at 11:01 am
Type 2	P1	3 mm	3 mm	10 mm	NM	0 mm	3 mm
	P2	6 mm	5 mm	16 mm	NM	0 mm	3 mm
	P3	6mm	8 mm	27 mm	NM	2 mm	3 mm
Type 2 twice ⁷	P4	24 mm	11 mm	-	8 mm	10 mm	-
	P5	58 mm	8 mm	-	18 mm	2 mm	-
	P6	30 mm		-	10 mm		-

Taking into account the rut results recorded immediately after rolling, the conclusions with regards to occasional rolling on these shoulders for the 4-wheel bogie of the A380-800F are as follows:

- type 2 section: acceptable (on the edge) after the experiment and therefore suitable for operational conditions normally less damaging (with most certainly a requirement to plan repair works of the shoulder following runway excursion and/or immobilization of a heavy aircraft on the shoulder).

type 2 twice section: unsuitable under the trial conditions. It is not possible to draw conclusions for operational conditions.

As with the first test, the importance of treated subgrade with weak structures is noticeable (this effect is more hidden for GLSR sections).

4) Conclusion

The conclusions with regards to occasional rolling on the different types of shoulders considered for the A380-800/ 800F 4-wheel bogie are as follows:

- type 1 section: acceptable after the experiment and therefore suitable for operational conditions normally less damaging. Moreover, this section was unaffected by static load for practically 18 hours without any visible damage. Therefore, the test is the most conclusive. This type of runway shoulders effectively fulfills the occasional rolling function of a large aircraft jet without any structural damage for the aircraft.

type 1 twice section: acceptable after the trial vehicle passage and therefore suitable for operational conditions normally less damaging. Residual damage was found afterwards that could require repair works.

type 3 section: unsuitable under experimental conditions. Nevertheless, for operational conditions, considering the level of the rut found it seems advisable not to recommend this structure for runway shoulders where heavy aircraft may operate.

type 2 twice section: unsuitable under the trial conditions. It is not possible to draw conclusions for operational conditions.

type 2 section: acceptable (on the edge) after the experiment and therefore suitable for operational conditions normally less damaging (with most certainly a requirement to plan repair works of the shoulder following runway excursion and/or immobilization of a heavy aircraft on the shoulder).

It is necessary to note that the classification of shoulder types according to their behavior during the tests is identical to that found following the plate tests (c.f. Preliminary Tests and Results page 3). Lastly, if the subgrade structure is very poor which would be difficult to be worse than that for this trial) treatment of the base associated with a relatively light structure (type 2) is highly appropriate.

It is important to underline that the conclusions deduced from this experimentation must always be analyzed regarding the experimental context of this test (Loading interference, repeatability...).

Recommendations

In conclusion, this experimentation tested five different shoulder structures. Without definitive conclusion it allows to confirm that several structures will be more suitable for occasional heavy aircraft passage.

A type 1 structure seems apparently oversized but offers the advantage of not requiring any maintenance in case of occasional aircraft passage.

With a low bearing strength subgrade the type 1 twice and type 2 structures should be certainly repaired when a runway excursion occurs.

Type 2 twice or type 3 structure used as in this test should certainly be redesigned with a low bearing strength subgrade, or replace by another structure.

This experimentation, regarding experimental context and the results uniqueness, brings useful and interesting information. However additional tests have to be planned to define complete technical reference.

Caution : it is important to notice that the structures were validated only for occasional passage heavy aircraft bogies. Thus in case of more frequent running over by ground vehicles during training it is necessary to size shoulders according to the roadway method and to select the most robust of the two structures.

APPENDICES

Appendix 1 - Purpose of shoulders

Appendix 2 - A380-800 landing gear

Appendix 3 – Photo plate Test 1: 4-wheel module, A380-800 trajectory 1 (direction type 2 to type 1)

Appendix 4 - Photo plate Test 2: 4-wheel module, A380-800 trajectory 2 (direction type 1 to type 2)

Appendix 5 - Photo plate Test 4: 2-wheel module; S trajectory (direction type 1 to type 2)

Appendix 6 - Photo plate Test 5: 4-wheel module, A380-800F trajectory 1 (direction type 1 to type 2)

Appendix 7 - Photo plate Test 6: 4-wheel module, A380-800F trajectory 2 (direction type 2 to type 1)

Appendix 1 - Purpose of shoulders

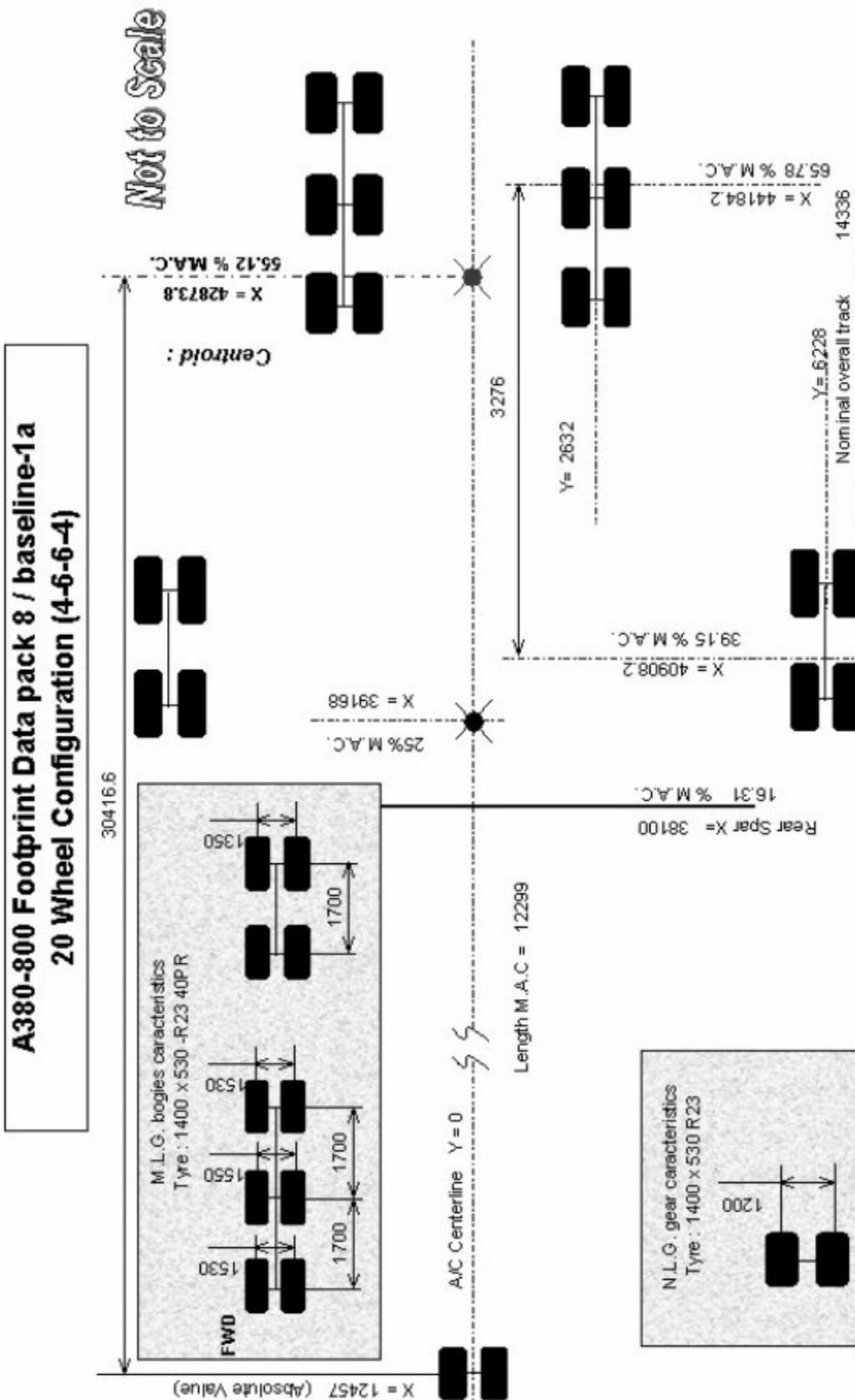
● Runway shoulders

Source	Document	§	Purpose of shoulders		
			Occasional overrunning by an aircraft	Fire vehicles access	Protection against blast (erosion + ingestion)
	ITAC	A-9-1	×	×	×
	ITAC	5-4	~	×	×
ICAO	Annex 14	3.2.5	×	×	Refer to ADM Part 1
ICAO	Airfield design manual (part 1)	5.2	×	×	×

● Taxiway shoulders

Source	Document	§	Purpose of shoulders		
			Occasional overrunning by an aircraft	Fire vehicles access	Protection against blast (erosion + ingestion)
	ITAC	C-4	0	×	×
	ITAC	5-4	~	×	×
ICAO	Annex 14	3.9.2	Refer to ADM Part 2	Refer to ADM Part 2	×
ICAO	Airfield design manual (part 2)	1.6	×	×	×

Appendix 2 – A380-800 landing gear



Appendix 3 – Photos

Test 1: 4-wheel module, A380-800 trajectory 1 (direction type 2 to type 1)



▲ Picture no. 1: trajectory test no. 1¹



▲ Picture no. 2: rut profile P2 centerline 2



▲ Picture no. 3: bogie sunk in Type 2 twice section



▲ Picture no. 4: bogie sunk in Type 2 twice section, rear view

¹ The white lines on the pavement are from the dust picked up by the tires when rolling from the PEP storage area to the shoulder test area. Very practical to visualize trajectories after rolling



▲ *Picture no. 5: front axle of bogie sunk in Type 2 twice section*



▲ *Picture no. 6: rut Type 2 twice section: symmetry*



▲ *Picture no. 7: rut Type 2 twice section after removal of the bogie*



▲ *Picture no. 8: rut Type 2 twice section after removal of the bogie (front axle in foreground)*



▲ *Picture no. 9: rut Type 2 twice section after removal of the bogie (maximum rut, front axle centerline 2)*

Appendix 4 – Photos

Test 2: 4-wheel module, A380-800 trajectory 2 (direction type 1 to type 2)



▲ Picture no. 10: Preparation for trajectory test no. 2



▲ Picture no. 11: Rut profile P12 centerline 1



▲ Picture no. 12: bogie sunk in Type 3 section: rear view



▲ Picture no. 13: bogie sunk in Type 2 twice section



▲ Picture no. 14: centerline 1 of bogie sunk in Type 3 section



▲ Picture no. 15: view centerline 2 of bogie; no sinking (asymmetry)



▲ *Picture no. 16: rear view, rut Type 3 section; asymmetry*



▲ *Picture no. 17: rut Type 3 section after removal of the bogie: view according to centerline 1 (front axle in foreground)*



▲ *Picture no. 18: rut Type 3 section after removal of the bogie (front axle in foreground)*



▲ *Picture no. 19: rut Type 3 section after removal of the bogie: view according to centerline 1 rear axle*

Appendix 5 – Photos

Test 4: 2-wheel module; S trajectory (direction type 1 to type 2)



▲ *Picture no. 20: Preparation of the 2-wheel module*



▲ *Picture no. 21: rolling of 2-wheel module on type 1 twice section*



▲ *Picture no. 22: S trajectory, type 3, 2 twice and 2 section (rutting on type 2 twice)*

◀ *Picture no. 23: S trajectory*



▲ *Picture no. 24: rutting on type 2 twice*

➤ *Picture no. 25: rutting on type 2 twice*



Appendix 6 – Photos

Test 5: 4-wheel module, A380-800F trajectory 1 (direction type 1 to type 2)



▲ Picture no. 26: Preparation for trajectory test no. 5



▲ Picture no. 27: Preparation for trajectory test no. 5



▲ Picture no. 28: rolling test no. 5, transition type 1 twice and type 3 section (rut test no. 2 in foreground)



▲ Picture no. 29: bogie sunk in Type 3 section



▲ Picture no. 30: bogie sunk in Type 3 section, view centerline 2



▲ Picture no. 31 rut type 3 section: practically symmetrical



▲ *Picture no. 32: surface material lifting*



▲ *Picture no. 33: surface material lifting*



▲ *Picture no. 34: rut Type 3 section after removal of the bogie (front axle in foreground)*



▲ *Picture no. 35: rut Type 3 section after removal of the bogie (rear axle in foreground)*

Appendix 7 – Photos

Test 6: 4-wheel module, A380-800F trajectory 2 (direction type 2 to type 1)



◀ Picture no. 36: Preparation for trajectory test no. 6



▲ Picture no. 37: rolling test no. 6: type 2 section



▲ Picture no. 38: bogie sunk in Type 2 twice section: view centerline 1



▲ Picture no. 39: bogie sunk in Type 2 twice section: view centerline 1



▲ Picture no. 40: bogie sunk in Type 2 twice section: rear view centerline 1



▲ Picture no. 41: rear view rut Type 2 twice section: dissymmetry



▲ *Picture no. 42: removal of bogie*



▲ *Picture no. 43: rut under centerline 1 Type 2 twice section after removal of the bogie (rear axle in foreground)*



▲ *Picture no. 44: rut under centerline 1 rear axle Type 2 twice section after removal of the bogie*