# Procedures & Use of SS21 in Soil Stabilization & Dust Control: Case of Study Kingdom of Saudi Arabia.

## 1-Introduction:

SS21 is a polymer used for Soil Stabilization and Dust-Control. The core application of the product is granular soils (Silty Sands, Sands, Gravels). It can be used in other kind of soils and applications.

As it is a product used for engineering purposes, the tests are to be developed using international standards, ASTM standards o equivalent for the case.

## 2-Particular application:

For this particular case and application, we'll focus on Sandy soil, in KSA area, where high temperatures, high evaporation rates are the usual condition. Thereof, any other application for other uses should be based on a more general document.

From now on, we will split the application of SS21 in 2 groups:

- Sand Stabilization: With main focus on roads, able to develop a structural layer. It also gives dust-control and waterproofing properties.
- Dust Control: With main focus on improving surfaces, mitigation of dust, and waterproofing. The layer of Sand+SS21 is minimum and non-structural.

## 3-Sand Stabilization with SS21:

Considering the main issue with the sand is the lack of cohesion and a pure frictional behaviour, SS21 is the solution that upgrades the quality of the top layer, and gives an excellent performance on surface for roads, even if the roads will be left unpaved.

The way of thinking SS21 in roads is a percentage of the volume of compacted sand. This means, we will talk about a percentage that means an amount of SS21 in kilograms per cubic meter of sand. The justification of this is that in roads engineering, we are focus in kilometres of roads, considering cubic metres of compacted sand, then is easy to get the kilometres or metres of roads, dividing the total volume in the typical section area.

SS21 is considered as part of the solution added to the soil. The soil need to be classified using HBR (ASTM D3282) and USCS (ASTM D2487) guidelines. The optimum water content (OMC) of Sand obtained from Proctor Standard ASTM D698 / Proctor Modified Test ASTM D1557. For most of the cases, Proctor Standard ASTM D698 is selected. After obtaining the OMC, that percentage should be covered with a solution of SS21+Water.

Strength tests are to be performed considering the OMC, for different SS21 concentrations. As usual practice, CBR – California Bearing Ratio (ASTM D1883) and UCS – Unconfined Compressive Strength (ASTM D2166) tests should be performed for different concentrations of SS21. Usual range for SS21 is between 10% of OMC to 50% of OMC. It means, the OMC should be covered using different amounts of SS21 and water. Considering the following table:

| SS21 and Water as % of OMC | | |
|---|---|---|
| **SS21%** | **Water %** | **Note** |
| 0 | 100 | No SS21, only water |
| 10 | 90 | Increasing amount of SS21 in solution |
| 20 | 80 | |
| 30 | 70 | |
| 40 | 60 | |
| 50 | 50 | 50% water+50% SS21 |

Please, take into account that the percentages shown are in terms of OMC. The OMC should be considered as a solution, partially covered by SS21 and partially covered by Water. A solution of 10%, means 10% of the OMC covered by SS21, and 90% covered by water. That is the way the percentages shown on *"Chemical stabilization of sands with SS21. Case of study: fine sands from the Argentinean Delta"* are constructed.

In terms of CBR and UCS tests, the recommendations is to use them for correctly address the strength and deformation needed for the particular project. Higher structural requirement will require higher CBR and UCS values.

CBR can be performed either on sand with and without SS21, to have a comparison. UCS is usually hard to be performed in sand without SS21, given the lack of cohesion. It is recommended for UCS to use a radiographic film or equivalent, to avoid adherence between mould and sample, making it impossible to extract the sample for testing the UCS. At this stage, CBR & UCS tests should be performed for increasing concentrations. CBR tests should be performed in unsoaked variant to let the product dry.

CBR:

- Unsoaked variant. Will be at least 3 samples, at 12, 25 and 56 strokes, 5 layers. The range of densities and moistures should cover the OMC and MDD obtained in the Proctor Standard test.
- 1 CBR test for 0% of SS21, meaning sand in natural condition. Will give the baseline value.
- 1 CBR test for each concentration of SS21, 10%, 20%, 30%, 40%, 50% of the OMC, meaning 5 tests. At this stage, also it is possible to develop 3 tests, at 10%, 20% and 30% as it is usual range of use.

UCS:

- UCS should be performed using the OMC as reference. Sample should be compacted at OMC in all cases.
- 1 UCS test for each concentration of SS21, 10%, 20%, 30%, 40%, 50% of the OMC, meaning 5 tests. At this stage, also it is possible to develop 3 tests, at 10%, 20% and 30% as it is usual range of use.

| CBR / UCS Test | | | |
|---|---|---|---|
| SS21% | Water % | UCS | CBR |
| 0 | 100 | N/A | 1 Test |
| 10 | 90 | 1 Test | 1 Test |
| 20 | 80 | 1 Test | 1 Test |
| 30 | 70 | 1 Test | 1 Test |
| 40 | 60 | 1 Test | 1 Test |
| 50 | 50 | 1 Test | 1 Test |

Samples should be tests after letting cure sundried in mould at least 72h. If there is no possibility of letting sundry, oven can be used in the range of 60º-100ºC.

Before testing the samples, be sure that they are in dry condition, to be able to unmould if needed, and to have comparable testing results.

Regarding all that, the amount of SS21 per cubic meter of soil should be covered to reach the percentage stated, and the rest should be covered with water. Note that the soil can contain natural moisture, but in this particular case, that amount should be negligible.

To obtain the amount of SS21 and Water per cubic meter, the measurements should be based on the above, converting the OMC to a volumetric quantity.

**Tables & Formulas:**

$$Solution\ OMC\ \left(\frac{kg}{m^3}\right) = MDD * OMC\ \%$$

$$SS21\ \left(\frac{kg}{m^3}\right) = Solution\ OMC\ \left(\frac{kg}{m^3}\right) * SS21\ \%$$

$$Water\ \left(\frac{kg}{m^3}\right) = Solution\ OMC\ \left(\frac{kg}{m^3}\right) * (100 - SS21\ \%)$$

*Where:*

$MDD$*: Maximum Dry Density obtained by ASTM D698.*

$OMC$*: Optimum Moisture Content obtained by ASTM D698.*

$Solution\ OMC\ \left(\frac{kg}{m^3}\right)$*: Weight of solution (SS21 + Water) to add per cubic metre.*

$SS21\ \left(\frac{kg}{m^3}\right)$*: Weight of SS21 to add per cubic metre at certain dosage.*

$Water\ \left(\frac{kg}{m^3}\right)$*: Weight of Water to add per cubic metre at certain dosage.*

Using this considerations, the following tables were made:

## Table to determine SS21 and Water amounts based on MDD and OMC (1/2)

| Soil | OMC | | SS21 0% | | SS21 10% | | SS21 20% | |
|---|---|---|---|---|---|---|---|---|
| MDD | Partial | Solution | SS21 | Water | SS21 | Water | SS21 | Water |
| kg/m$^3$ | % | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ |
| 1400 | 5 | 70 | 0 | 70 | 7 | 63 | 14 | 56 |
| | 10 | 140 | 0 | 140 | 14 | 126 | 28 | 112 |
| | 15 | 210 | 0 | 210 | 21 | 189 | 42 | 168 |
| | 20 | 280 | 0 | 280 | 28 | 252 | 56 | 224 |
| 1500 | 5 | 75 | 0 | 75 | 8 | 68 | 15 | 60 |
| | 10 | 150 | 0 | 150 | 15 | 135 | 30 | 120 |
| | 15 | 225 | 0 | 225 | 23 | 203 | 45 | 180 |
| | 20 | 300 | 0 | 300 | 30 | 270 | 60 | 240 |
| 1600 | 5 | 80 | 0 | 80 | 8 | 72 | 16 | 64 |
| | 10 | 160 | 0 | 160 | 16 | 144 | 32 | 128 |
| | 15 | 240 | 0 | 240 | 24 | 216 | 48 | 192 |
| | 20 | 320 | 0 | 320 | 32 | 288 | 64 | 256 |
| 1700 | 5 | 85 | 0 | 85 | 9 | 77 | 17 | 68 |
| | 10 | 170 | 0 | 170 | 17 | 153 | 34 | 136 |
| | 15 | 255 | 0 | 255 | 26 | 230 | 51 | 204 |
| | 20 | 340 | 0 | 340 | 34 | 306 | 68 | 272 |
| 1800 | 5 | 90 | 0 | 90 | 9 | 81 | 18 | 72 |
| | 10 | 180 | 0 | 180 | 18 | 162 | 36 | 144 |
| | 15 | 270 | 0 | 270 | 27 | 243 | 54 | 216 |
| | 20 | 360 | 0 | 360 | 36 | 324 | 72 | 288 |

## Table to determine SS21 and Water amounts based on MDD and OMC (2/2)

| Soil | OMC | | SS21 30% | | SS21 40% | | SS21 50% | |
|---|---|---|---|---|---|---|---|---|
| MDD | Partial | Solution | SS21 | Water | SS21 | Water | SS21 | Water |
| kg/m$^3$ | % | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ |
| 1400 | 5 | 70 | 21 | 49 | 28 | 42 | 35 | 35 |
| | 10 | 140 | 42 | 98 | 56 | 84 | 70 | 70 |
| | 15 | 210 | 63 | 147 | 84 | 126 | 105 | 105 |
| | 20 | 280 | 84 | 196 | 112 | 168 | 140 | 140 |
| 1500 | 5 | 75 | 23 | 53 | 30 | 45 | 38 | 38 |
| | 10 | 150 | 45 | 105 | 60 | 90 | 75 | 75 |
| | 15 | 225 | 68 | 158 | 90 | 135 | 113 | 113 |
| | 20 | 300 | 90 | 210 | 120 | 180 | 150 | 150 |
| 1600 | 5 | 80 | 24 | 56 | 32 | 48 | 40 | 40 |
| | 10 | 160 | 48 | 112 | 64 | 96 | 80 | 80 |
| | 15 | 240 | 72 | 168 | 96 | 144 | 120 | 120 |
| | 20 | 320 | 96 | 224 | 128 | 192 | 160 | 160 |
| 1700 | 5 | 85 | 26 | 60 | 34 | 51 | 43 | 43 |
| | 10 | 170 | 51 | 119 | 68 | 102 | 85 | 85 |
| | 15 | 255 | 77 | 179 | 102 | 153 | 128 | 128 |
| | 20 | 340 | 102 | 238 | 136 | 204 | 170 | 170 |
| 1800 | 5 | 90 | 27 | 63 | 36 | 54 | 45 | 45 |
| | 10 | 180 | 54 | 126 | 72 | 108 | 90 | 90 |
| | 15 | 270 | 81 | 189 | 108 | 162 | 135 | 135 |
| | 20 | 360 | 108 | 252 | 144 | 216 | 180 | 180 |

In high temperature environments and high evaporation ratios, it is usual practice in roads to add more water, to supply this loss of water. As well, high permeability soils, tend to generate a leakage of fluids into the soil mass, that requires probably and additional amount of water. All this parameters are determined on site experimentally, as small corrections.

The general procedure will be as follow:

1. **Determine the type of soil:** Soil should be classified for road purposes using the HRB classification (ASTM D3282) and USCS classification (ASTM D2487). It requires to develop Atterberg limits tests (ASTM D4318), if possible, as sand usually has low to null plasticity. Particle size distribution (PSD) should be determined using ASTM D1140 for material finer than mesh Nº200, and ASTM D6913 for materials above mesh Nº200, considering that both tests are necessary to asses a proper granulometric curve. If the amount of fines is above 5%, also ASTM D7928 should be carried out for hydrometric analysis.

2. **Determine general parameters of the soil for compaction** (OMC= Optimum Moisture Content, MDD=Maximum Dry Density). This can be only determined by ASTM D698, or ASTM D1557. Refer to ASTM D698 for Proctor Standard Test, which is used in most of the cases. For strength and deformation considerations, tests should be carried out based on CBR (ASTM D1883) and UCS (ASTM D2166), for a range from 0% to 50% of SS21 concentration of the OMC.

3. **Determine the volume of soil to be used:** Consider compacted soil, to be independent from swelling/compaction factor. The volume will be easily calculated then by geometry, e.g. Length*Section = Volume. Unit in meters and then take it in $m^3$. The height of the layer will be determined by structural requirements, most of the applications should fall in a range between 150mm to 200mm.

4. **Consider the percentage of SS21 to be used based on requirements:** The usual range of SS21 is from 10 to 30% of the OMC based on traffic of structural requirements. The appropriate amount to be used, will depend on the CBR and UCS values and comparing that result with the specifications.

5. **Mix the SS21 in the water container:** For roads use, water trucks with sprinklers is the normal practice. Considering this, is good practice to add SS21 and water in the container in steps, 1/3 of the tank with 1/3 of SS21 content, or similar, making a mix, moving the truck back and forth to generate a mixing effect. Additional mechanical mixing can be used, but it is not needed, as both densities are close. Using the considerations in point 3, should be easy to calculate volumes needed. The amount of water can be more, to fulfil the temperature/evaporation requirements, but the percentage of SS21 per volume should be covered appropriately. There is no settling time for SS21, can be instantly distributed into the soil.

6. **Dig/build-up or Scarify the soil and mix SS21:** Regarding the application, in some cases, digging or building up will be needed to reach project levels. After that process, to integrate SS21 in the soil, the layer should be scarified, to allow the SS21 to permeate into the layer. SS21 need to be mixed with the soil appropriately. The procedure is the same as the usual practice in roads.

7. **Apply SS21 into the soil and mix appropriately:** SS21 should be applied with the Water trucks, using sprinklers, as the normal addition of water for the soils during compaction. It is important to keep record of the amount of SS21 delivered into the soil that can be easily tracked taking note of the volume of solution applied per meter of road, experimentally. SS21 need to be mixed with the soil appropriately, to cover the full surface of each sand grain.

8. **Compaction process:** The soil should be compacted as normal practice in roads, using for Sands the vibratory road roller. There is no special requirement, the normal practice for roads on that area should be followed, as it account for the experimental solution. After compacting the soil, in some cases there is a settling time needed. For this particular case, high temperature/evaporation and sandy soil, the settling time should be negligible. Normal layers of 150mm to 200mm are the usual, with a minimum of 8 to 10 back and forth of normal roller. Take into account that if a smaller compacter is used, more and thinner layers are required for compaction, and more back and forth with roller.

9. **Final spray:** For some applications, where a smoother finishing or enhanced waterproofing is required, a final spray of SS21 can be applied following the guidelines of Dust Control.

10. **Cleaning of the Water truck:** It is recommended to clean the water truck with water, to be sure that there is no remaining of SS21 in the empty tank, that can obstruct sprinklers or coat the tank from inside. Shouldn't be an issue, but is good practice to take this point into consideration.

11. **Final testing:** For assessing the final condition of the road, several tests can be performed for determining the strength and deformation values for the case. Plate Load Tests (ASTM D1196) can be performed, or equivalent/similar tests, to obtain a reference for CBR values.

The results obtained for OMC and MDD, in the paper *"Chemical stabilization of sands with SS21. Case of study: fine sands from the Argentinean Delta"* are estimated as follow:

| CBR / UCS Test Results | | | |
|---|---|---|---|
| SS21 | Water | UCS | CBR |
| % | % | kg/cm$^2$ | % |
| 0 | 100 | 0.00 | 33.89 |
| 10 | 90 | 2.40 | 50.12 |
| 20 | 80 | 9.24 | 76.50 |
| 30 | 70 | 16.17 | 83.04 |
| 40 | 60 | 18.77 | 98.29 |
| 50 | 50 | 21.66 | 138.96 |

This results are for an order of magnitude and will defer from soil to soil. This table should not be used, instead, results from tests are important to determine any parameter needed for engineering design. It is important to remember that SS21 applied in Sand Stabilization confer to the build-up:

- Improving of resistance and deformation parameters.
- Adherence between particles, and dust-control.
- Waterproofing properties.
- Enhanced durability, by improving resistance and reducing erodability.

**Worked Example 1 – Soil Stabilization:**

5m wide and 1km length road on sand.

Consider 150mm thick layer.

MDD= 1700 kg/m$^3$.

OMC= 10%.

SS21 used at 20% replacement of OMC.

- Calculate the unit amount of water & SS21:

$$Solution = MDD * OMC$$

$$Solution = 1.700\frac{kg}{m^3} * 10\% = 170\frac{kg}{m^3}$$

$$SS21 = Solution * 20\% = 34\frac{kg}{m^3}$$

$$Water = (Solution) - (SS21\ ) = 136\frac{kg}{m^3}$$

- Calculate Compacted Volume:

$$Volume = 5m * 1000m * 0.15m$$

$$Volume = 5.000m^3$$

- Calculate Total amount of Water & SS21:

$$Total\ SS21 = SS21 * Volume = 34\frac{kg}{m^3} * 5.000m^3$$

$$Total\ SS21 = 170.000kg$$

$$Total\ Water = Water * Volume = 136\frac{kg}{m^3} * 5.000m^3$$

$$Total\ Water = 680.000kg$$

## 4-Dust Control with SS21:

Another application of SS21 is the dust-control, basically reducing the transport of airborne particles by creating an adherence between them in the top layer.

Regarding this, SS21 is applied in solution by spray over a surface, creating a thin layer of treated soil. It is important to note that this layer is not structural, and it is not recommended for traffic. If there is a structural requirement for the layer, Sand Stabilization with SS21 procedure is recommended.

On this particular case of high temperatures and high evaporation ratio, on a Sandy soil, it is possible that more water in the solution is required to fulfil the water demand. As well, more water in the solution reduces the viscosity, giving more permeation capabilities to the solution.

Applying SS21 is a simple process: A concentration is defined, and then the solution is applied by spray over the surface. As the use of SS21 will be on a surface, square meters or equivalent is the appropriate unit.

SS21 will be applied for this particular case in a range between 5 to 10% in solution for most of the cases. This means, from the total volume of solution, 5 to 10% of the same will be SS21, and 90 to 95% will be water respectively.

The permeation and the thickness of the penetration in the top layer, must be determined experimentally, as this parameter varies from site to site. For a general reference, the thickness of the permeation increases with the amount of water in the solution, with the permeability of the soil, and the number of times it is sprayed. Keep in mind, that in this particular case, the SS21 will dry quickly, creating a superficial waterproofing layer, that will not allow of a 2$^{nd}$ or 3$^{rd}$ time application. If there is a need for a particular thickness, a more detailed analysis is needed.

Considering the above, the general procedure will be as follow:

1. **Determine the type of soil:** Sand in this case. Medium to high permeability soil.

2. **Determine the area of the surface to be treated:** The area to be treated will be in $m^2$, and can be easily calculated.

3. **Consider the percentage of SS21 to be used based on requirements:** For general uses, 5% to 10% of SS21 in solution is enough. For 5% it means 5 litres each 100 litres of solution (95 litres of water), and for 10% it means 10 litres each 100 litres of solution (90 litres of water). From our experience, 1 litre of solution is enough to cover 1m$^2$. Sprinklers cover area and estimated flow, will give an estimation of water truck velocity, if applied that way. All these considerations should be determined experimentally.

4. **Mix the SS21 in the water container:** The procedure is the same as for Sand Stabilization mix in the water truck. 10.000 litres of solution will cover 10.000 m$^2$. For 5% of SS21, it will be 500 litres of SS21 and 9.500 of water. For 10% of SS21, it will be 1.000 litres of SS21 and 9.000 litres of water.

5. **Apply SS21 into the soil:** SS21 will be applied by spray. As it was said before, additional water can be added to the truck, for taking temperatures and evaporation into account. Truck velocity, sprinklers coverage area, sprinklers flow, and truck storage volume are relevant parameters for the estimation. This will be determined experimentally. Shouldn't be any requirement for settling, and for this particular case, SS21 will dry quickly.

6. **Cleaning of the Water truck:** It is recommended to clean the water truck with water or SS21-Antidote, to be sure that there is no remaining of SS21 in the empty tank, that can obstruct sprinklers or coat the tank from inside. Shouldn't be an issue, but is good practice to take this point into consideration.

More complex cases can appear, in those cases particular solutions can be considered, as inundation, pressurised spray or confined applications, but for most of the cases, the procedure stated above should be enough.

Note that SS21 % is usually between 5 to 10%. 10% is recommended based on our experience.

A simple worked example is shown below:

**Worked Example 2 – Dust-Control:**

Roadside, 5m wide each side.

Length= 1 km.

Road on Sand.

SS21 used at 10%.

- Calculate Area:

$$Area = 5m * 2 * 1000m$$

$$Area = 10.000m^2$$

- Calculate Solution:

$$Solution = (1\ \frac{litre}{m^2}) * (10.000m^2)$$

$$Solution = 10.000\ litre$$

- Calculate amount of water, SS21:

$$SS21 = (Solution) * (SS21\ \%) = 10.000\ litre * 10\%$$

$$SS21 = 1.000\ litre$$

$$Water = (Solution) * (1 - SS21\ \%) = 10.000\ litre * 90\%$$

$$Water = 9.000\ litre$$

It is recommended to do specific test with the material to be used, as this results may defer from final application.

It is important to remember that SS21 applied in Dust Control confer to the surface:

- Adherence between particles, and dust-control.
- Waterproofing properties.
- Enhanced durability, by improving resistance and reducing erodability.

Note that it is not a structural layer.

## 5-Final Comments:

Up to this point, the solution for Sand Stabilization and Dust-Control has been clearly specified for Sands in KSA, in high temperatures and high evaporation rates environment.

Note that it is not recommended to directly extrapolate this document to other soils or environments, without taking into consideration all the parameters needed for the case.

All the parameters stated are based on experience and testing, using mainly Argentinean Sands from Argentinean Delta, as stated in the document: *"Chemical stabilization of sands with SS21. Case of study: fine sands from the Argentinean Delta"*. It is recommended to do lab and site tests with the local sand on use, to refine the experimental data.

Special applications will need a special treatment and procedure, engineering considerations and design is needed to verify the physical behaviour of more complex solutions.

Do not hesitate to contact any member of the team for more detail on this.

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