GYRATORY COMPACTOR 77-B251 RESEARCH MODEL  
A Case Study – Two Years of Testing

The use of the gyratory compactor to design and control bituminous mixes is becoming more and more widely used. In the United States the SUPERPAVE program developed by the Strategic Highway Research Program (SHRP) and in Europe through the European Standard prEN 12697-9 the use of the gyratory compactor is the fundamental instrument for laboratories dedicated to the design and control of bituminous pavements.

It is well known that the gyratory test defines the mix by its volumetric characteristics. A given sample mass, heated to its optimum temperature in function of the bitumen viscosity required during pavement laying, is held within a cylindrical steel mould and then subjected to two simultaneous actions by the compactor. A vertical static compression and a gyratory action consisting of a rotation with an axial offset of the cylinder mass with respect to the vertical axis of the compactor’s load ram. The normal angles are 1.25° for Superpave and 1° for the European Standard.

The rotational frequency and vertical pressure is the same for both methods, that is 30 gyrations per minute and 600 kPa respectively.

The sample is thus compacted and its density measured continuously. For a given type of mix, keeping the gyratory angle, frequency and vertical pressure constant, the degree of compaction will depend upon the number of gyrations made by the machine.

The software supplied with the compactor continuously reads the sample height using an on board displacement transducer and displays the sample height, density, percentage voids, percentage voids mixed aggregates (VMA), percentage voids filled bitumen (VFB) and percentage of max theoretical density (Gmm) for each gyration.

Finally a curve is drawn which is approximately a straight line of percentage max theoretical density against the number of gyrations which is shown on a log scale on the horizontal axis. Three points corresponding to the three characteristic numbers of gyrations, that is N initial, N design, and N max are plotted on the graph.

Since the general principle of the test is to densify the sample up to a maximum value above which the densification curve no longer follows a straight line, the final number of gyrations, N max, will be such for any given mix, to give a densification of =<98% of the maximum theoretical density.

The slope of the curve is defined by the values of densification corresponding at the number of initial gyrations (N initial) and final gyrations (max).
The N design number is noted along this curve where the 96% of theoretical max density is reached, that is 4% voids content. These three gyration numbers are linked by the following equations (as per Superpave)

\[
\log N_{\text{initial}} = 0.45 \log N_{\text{design}} \\
\log N_{\text{max}} = 1.10 \log N_{\text{design}}
\]

The density value at N initial corresponds to the initial densification at the beginning of pavement rolling, whilst that at N design is the design densification that is to be reached at the completion of rolling. Therefore, the road contractor should furnish the pavement with this design density, with a predefined voids content, so as to guarantee a pre-set life span of the pavement corresponding to the density at N max, above which, with a residual percentage voids of less than 2%, the decrease in resistance to pavement deformation is amplified.

From this conceptual standpoint a few considerations can be drawn:

- mixes which give a steep densification curve indicate those with high compactibility. Their structure, consisting of an appropriate dose of bituminous binder and graded aggregates with high angularity, will absorb a high degree of compaction energy or in-situ rolling. Vice versa, mixes which present a densification curve with a low slope are characterised by poor compactibility.

- good compactibility corresponds to good resistance to permanent deformation. Indeed, the high compaction energy can well position the interlocking aggregate pieces in the mix structure. The resulting internal friction guarantees deformation resistance of the mix in situ.

Consequently, the design and control of the mix with the gyratory compactor relates to the “life” of the pavement with the compaction energy, expressed in terms of passing equivalent axle loads at a given weight (for Superpave this is 80 kN) which the pavement can support without permanent deformation.

With the gyratory compactor the energy is determined by the number of gyrations whilst the in situ energy is determined by the rolling intensity. Thus a family of densification curves will be available, these having limits of percentage of maximum theoretical density at the beginning of the test, N initial, (normally about 10 gyrations) and the percentage of max theoretical density at the end of the test, N max, conditioned by the limits of <=89% and <=98% respectively. (table)
From this brief description of the gyratory test, it becomes apparent that the volumetric method is associated to rheological aspects. It can be seen that it is the internal friction that determines the duration of the test, that is the number of gyrations to reach the density at N max. This friction is closely correlated to the shear force that the compactor must overcome during the test. It should be remembered that the gyratory compactor imparts two distinct compaction energies, a vertical pressure and a gyratory shear movement. The shear movement, combined with the vertical pressure, allows the aggregate pieces to move to a closer reciprocal distance so as to become more dense.

The gyratory movement generates a shear force whose entity depends upon the structure of the mix.

Controls research gyratory compactor (model 77-B251) differs from the standard model in that it measures the shear force. This is achieved with a special load cell housed in the vertical load ram. With the aide of a PC and the installed software it is possible to read the maximum shear force at each gyration. Therefore the test report will present a table with shear force (kN/sq.m) together with the other parameters normally associated with the gyratory test (sample height, density, voids, VMA, VFB) at the various gyrations.

The geometrical configuration of the sample during the test corresponds to a cylinder whose axis is slightly inclined with respect to the vertical by, for example, 1.25°. This angle rotates completely about the vertical axis producing a determinate shear movement with each gyration.

This movement can be represented by the scheme shown below where the sample is divided in finite elements (scheme).

Each element creates a shear effect on the adjoining element. Since the sample is confined within the cylindrical mould and the upper and lower platens having a constant vertical pressure supplied by the ram, the deformation force of the sample is measured by the reaction moment. The direction of the moment vector, normal to the rotation axis, rotates horizontally together with the gyratory movement, whilst the relative force acts against the bases of the cylinder. Since the measurement sensor is influenced by the reaction acting on the upper pressure plate (not that on the lower plate), an average shear force is calculated which takes in consideration the sample cross sectional area and sample height which continues to decrease with each gyration. The shear force is expressed in kN/sq.m. The maximum shear forces we have measured in experimentation vary between 300 and 400 kN/sq.m (graphs).
One may rightly observe that the measured values include the friction induced by the sample on the sides of the cylindrical mould walls during the compaction. Whilst this is true in the determination of the absolute shear value, it becomes negligible if the measurements are used in terms of normalised values, that is the percentage ratio with respect to a given value, for example the maximum recorded value during the test, as we have done in the analysis of many tests hereunder. What is more, in this way we have the possibility to compare the behaviour of the shear force between various bituminous mixes of the same type.

The machine used in our studies was installed about 2 years ago at an asphalt plant in San Donato, Milan, Italy (Impresa Bacchi). This company is well respected in the sector and has equipped itself to a standard above that currently requested by its clientele, in that it’s basic philosophy is to offer the maximum criteria of quality control available. Hence its decision to buy the research version gyratory compactor instead of the standard model.

During these two years Controls has been able to closely follow the use of this machine, not only in the course of its normal after sales activity but also to study the advantages presented by the measurement of shear force even if this is not required by current contractual obligations.

It became evident from the outset that the shear force measurement gave a useful indicator to the operator on the performance of the bituminous mix. Indeed the concept of correlating the slope of the densification curve, in substance the compactibility, to the shear resistance of the compacted material is implicit in Superpave. If one considers the importance dedicated to compaction energy in the European Standards, the shear measurement is also important here.

Having measurements, comparable between each other, of shear forces during tests, we realised that we had a useful research tool, which allows the investigation of the relationship between this parameter and other parameters. As a conclusion it was hoped to enhance the knowledge gained during the gyratory test, to further increase and refine the requisites of the bituminous conglomerates to meet ever increasing specifications.

Thus Controls has been able to study the results of a great number of tests made during this period. Five types of bituminous conglomerates have been considered. A base mix with natural bitumen with penetration 60/70 with 10% recycled. A base mix with bitumen 60/70 modified hard with 10% recycled. A binder with bitumen 60/70 modified hard with 10% recycled. A wearing mix bitumen 60/70 modified soft with 10% recycled. A drained wearing mix with bitumen 60/70 modified hard.
For each test we considered the value of two parameters calculated by the macro program: The voids content (V%) and the percentage of voids filled bitumen (V.F.B.). These two parameters were plotted on a graph against % of max shear force read at the characteristic gyrations N initial, N design and N max.

For now we have not considered the data to the drained wearing mix, but rather those generically termed as “closed”

By examining the distribution of the data of percentage of max shear force against voids (V%) at N design and N max one can note an evident increase in percentage maximum shear force with an increase in V% measured in various tests.

This tendency presents an asymptote pattern and can be described by:
\[
y = 100 - \frac{A}{B^x}
\]
The behaviour of percentage of maximum shear force with regards to VFB also appears asymptote but opposite to the above and can be described by:
\[
y = 100 - \frac{A}{B^{-x}}
\]
Contrary to the V%, with a decrease of V.F.B. the percentage of maximum shear force of the single tests increase in an asymptotic manner towards 100%.

These opposite tendencies are in reality coherent between each other. Indeed, for a given mix and given increase in compaction energy, during the gyratory test the positioning of the aggregate particles is continually changed with a resultant shear force. As the densification proceeds the absolute value of the shear force tends to decrease. This decrease, which we have called the percentage decrease of absolute maximum shear force recorded during the test, is caused by the lubricating effect of the bituminous binder.

The opposite behaviour, also exponential, is noted if we examine the graphs of percentage maximum shear against V% and against V.F.B. at N initial.

With an increase in V% one notes a decrease of percentage maximum shear force and consequently, with an increase of V.F.B. one notes an increase in percentage maximum shear force. At N initial, normally 10 gyrations, the conglomerate has not densified much, thus the effect of the friction between the aggregate is more significant than the lubricating effect.
We considered it useful to generalise these tendencies by presenting graphs which group the data relative to the four conglomerates under study at N initial, N design and N max, with the correlation of the percentages of the maximum shear values with V% and VFB. When studying the drained wearing mix, we did not note any correlation between the behaviour of the shear force and the densification of the material ( ). In fact, when this mix is in situ, it’s characteristic at N design of the test is a very high V%, approximately 18% and it would appear evident that the shear force is determined above all by the friction due to the angularity of the aggregates rather than the increase in the degree of densification. Indeed we should note that between N design (50 gyrations) and N max (130 gyrations) one typically obtains only a three points reduction in V%.

Naturally the data of our study are subject to discontinuity in that they refer to data collected in real working conditions and not ad hoc research mixes. However, for this very reason, we think we have reached some very interesting correlations which confirm the validity of reading shear forces.

The aforementioned correlations illustrate only one aspect of the research potential made available by the measurement of shear force during the gyratory test. In conclusion we think it would be useful to continue the studies to evaluate correlations with various graded aggregate, aggregate angularity, binder type, modified bitumen, dosage, and other parameters and test conditions so as the gyratory compactor can be used to its fullest potential in the design and control of bituminous pavements.

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