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SAP 2000 Validates Deflection in Multilayer Test

Sabaruddin[1]
[1]Universitas Khairun, North Maluku, Indonesia

Corresponding author e-mail: sabaruddin.abuahmad@gmail.com

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Abstract: Multilayer testing is one of the non-standard testing methods that has the potential to be developed in the future, so it requires special validation of its results. In this study, validation was carried out using SAP 2000 software, focusing on the calculation of downward curvature that occurs under the concrete layer. The study was conducted on test objects in closed conditions with certain dimensions. The test results showed that there was a difference between the downward curvature values produced from multilayer testing and calculations with SAP 2000. The difference in downward curvature between the two methods was recorded at 15.29%. This difference indicates that more validation is needed to ensure the accuracy of the multilayer testing method in future structural applications.

Keywords: Deflection, Index Terms-Multilayer, SAP 2000

A. Introduction

Technological developments in civil engineering continue to drive the creation of various new testing methods to ensure the quality and reliability of building structures. The increasing complexity of modern construction projects, involving composite materials and layered structures, requires a testing approach that is able to capture the dynamic properties of the various materials used. One method that is being developed and widely used is multilayer testing (Guangwu et al., 2020), which aims to understand the behavior of materials composed of several layers (Yan et al., 2020), such as reinforced concrete or composites (Dewangan & Panda, 2022). This approach provides deeper insight into the interaction between layers of material in resisting external forces and affecting the overall durability of the structure.

Along with the development of material technology, the use of composite materials consisting of several layers with different characteristics has become common in various construction applications, such as bridges, skyscrapers, and highway infrastructure (Sahu et al., 2021). These multilayer materials are designed to increase durability, strength (Cao & Ren, 2020), and resistance to external loads (Zhou & Jing, 2020), such as wind loads, earthquakes, and traffic loads. Multilayer testing is important because various types of modern construction materials often consist of several layers that are designed to work synergistically. For example, a concrete layer reinforced with steel not only increases the load capacity but also provides additional stiffness, which extends the service life of the structure.

This multilayer testing also serves to ensure that each layer of material can function optimally in bearing the given load. In civil engineering, simulation of structural behavior through multilayer testing, both experimentally and numerically, is crucial to predict potential failure or deformation that can occur during the service life of the structure. With the right testing method, engineers can validate designs, make early corrections to technical problems, and ensure that building structures meet applicable safety standards (Grozdanic et al., 2023). Simulation with software such as SAP 2000 (You et al., 2020) is one of the most useful tools to support multilayer analysis, allowing engineers to predict structural responses more efficiently and precisely. In a civil engineering laboratory, multilayer testing aims to simulate the loads faced by layered structures in real conditions (Ramteke & Panda, 2023). This testing involves various mechanical approaches (Hamim et al., 2020), such as flexural testing (Zhang et al., 2022), compression (H. Wang et al., 2021), and shear (Wiener et al., 2021), to assess material behavior under the influence of layered loads (Deng et al., 2022). In this case, the validity of multilayer testing is crucial, considering the complexity of the interactions between layers that require high accuracy in measurement (Szparaga et al., 2020).

The multilayer method is designed to test the behavior of materials composed of several layers in building structures. However, due to its relatively new nature (Ecker et al., 2020), multilayer testing requires validation in order to be reliable and widely recognized as a valid method in structural testing (Shan et al., 2022). Test validity is essential to ensure that the method used meets international testing standards (Kim et al., 2023). The use of structural analysis software, such as SAP 2000, is an integral part of the test validation process (Han et al., 2020). SAP 2000 software allows predicting the behavior of structures (Y. Wang et al., 2024), including downward bending that occurs beneath layers of concrete or other materials. However, differences between laboratory test results and computer simulation results often occur, requiring further study to improve the accuracy and reliability of the multilayer test method.

To ensure the validity of SAP 2000, this study also used the Indonesian National Standard (SNI) 19-17025-2000, which was later revised to SNI ISO/IEC 17025:2008, which refers to ISO/IEC 17025:2005 which regulates the requirements for the competence of testing and calibration laboratories, including method validation. Based on SNI ISO/IEC 17025:2008. To prove that a particular method meets the requirements and produces consistent and accurate results, validation includes empirical testing to ensure that each stage of testing has met the established standards.

Multilayer testing on a laboratory scale test object with a static load centric monotonic, following the loading procedure according to ASTM D1194-72, in this case simultaneously using a set of test tools in the form of a steel frame, steel box (enclosed on all four sides), hydraulic jack, and transducer (canister type load cell, strain gauge type PMFLS-60 asphalt, concrete strain gauge type PL-60, LVDT or linear variable differential transducer, soil pressure gauge) as well as the data logger and a computer station and its programs. Testing begins with the determination of geometric specimen, the thickness of the layers of porous asphalt according to the thickness used by Pusjatan in the North Coast, the thickness of the layers of cement concrete and reaction subgrade following the guidance on the structure and building planning of road pavement cement concrete, which was published by the department of settlement and regional infrastructure (Pd T-14-2003).

The SAP (Structural Analysis Program) is a program structure analysis using the Finite Element Method and is able to analyze static and dynamic problems. SAP Software was developed starting in 1970 by Prof. Edward L. Wilson and Ashraf Habibullah from the University of California, Berkeley California USA. This software initially can only work on mainframe computers (Dewangan et al., 2022).

This research has an innovation in the development and validation of multilayer testing methods that have not been widely applied in civil engineering laboratories. This research not only focuses on the implementation of multilayer testing methods, but also validates the method using SAP 2000 structural analysis software, which is a modern computational approach to predicting the behavior of layered materials under load. The difference between the results of direct testing in the laboratory and simulations carried out through SAP 2000 can identify and correct inconsistencies in the multilayer testing method. The results of this study are expected to provide new contributions by strengthening the accuracy and reliability of multilayer testing, as well as ensuring that this method is feasible to be implemented more widely in civil engineering laboratories in the context of layered material testing that is increasingly relevant in the modern construction world. This research also forms the basis for the development of new standards in multilayer testing methods that combine empirical validation in the laboratory with computer simulation, creating a more comprehensive approach to assessing the quality and strength of layered materials.

This research focuses on the validation of multilayer testing against deflection that occurs under the concrete layer using SAP 2000 software as a simulation tool. Testing is carried out in closed conditions with a maximum load of 126.78 kN. The purpose of this study is to understand the differences between the deflections resulting from experimental multilayer testing and the deflections resulting from SAP 2000 simulations, and to determine whether these differences are still within reasonable limits.

B. Methods

This study uses a quantitative approach to test the validity of the multilayer testing method on layered materials, both experimentally in the laboratory and through computer simulation using SAP 2000 software (Singh et al., 2021). This testing involves a series of procedures that follow international standards, including ASTM D1194-72 and SNI ISO/IEC 17025:2008, which regulate the competence and validation of laboratory methods.

Experimental Testing

Laboratory testing is carried out by applying loads to layered structures and measuring the resulting deflections. These layered structures generally consist of several materials such as concrete, asphalt, and subgrade layers arranged sequentially to mimic real conditions on highways or building structures. The standard used in this testing is ASTM D1194-72, which specifies procedures for deflection testing on pavements that receive loads. ASTM D1194-72 ensures that static and dynamic load tests are carried out accurately, taking into account factors such as axial load, material modulus of elasticity, and pressure distribution in the layers

Experimental Design

Multilayer testing is carried out on laboratory-scale test objects with monotonic centric static loads. The loading procedure follows ASTM D1194-72 using a set of test equipment including (1) Steel frame and steel box closed on all four sides. (2) Hydraulic jack. (3) Transducer in the form of canister type load cell, PMFLS-60 type strain gauge for asphalt, PL-60 type concrete strain gauge for concrete, LVDT (Linear Variable Differential Transducer), and soil pressure measuring instrument. (4) Data logger and computer to record data during testing. Testing begins by determining the geometric specimen, where the thickness of the porous asphalt layer and cement concrete is adjusted to the guidelines used in Indonesia, such as those published by Pusjatan on the Pantura route and Pd T-14-2003 for cement concrete road pavement.

Computer Simulation Using SAP 2000

SAP 2000 software is used to validate laboratory test results through computer simulation. SAP 2000 is based on the Finite Element Method (FEM) which is capable of analyzing static and dynamic problems. The simulation aims to (1) predict the behavior of layered structures under load. (2) Compare simulation results with laboratory test results to find differences and discrepancies. With this validation, SAP 2000 acts as an analysis tool to improve the accuracy and reliability of multilayer testing.

Test Validation

The validation process is carried out based on the SNI ISO/IEC 17025:2008 standard, which refers to ISO/IEC 17025:2005. This standard ensures that the methods used in testing meet international requirements for laboratory competence and calibration. Test validation includes (1) Empirical testing to ensure consistent accuracy of results. (2) Comparison between laboratory test data and SAP 2000 simulation results.

Data Analysis

Data obtained from laboratory testing and SAP 2000 simulations were statistically analyzed to evaluate the differences between physical test results and simulation results and the validity of the multilayer test method as a valid and reliable method in testing layered materials. After validation, the results of this study provide a basis for the development of multilayer test standards in civil engineering laboratories. In addition, this study aims to improve the accuracy and reliability of the multilayer test method so that it can be used more widely in the modern construction world.

Test objects

Dimensions and illustrations of the test specimen, material properties, as well as testing settings and installation tools, and visualization of the results can be seen in Figure 1, Figure 2, and in Table 1 below:

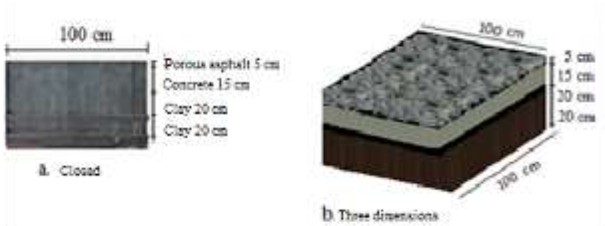

Figure 1. Test object

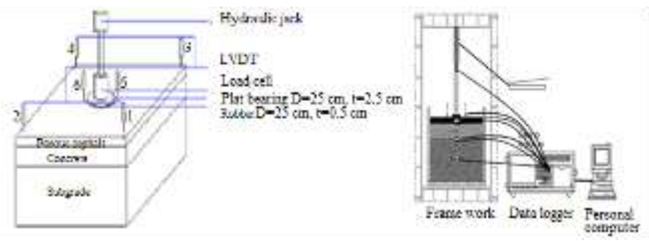

Figure 2. Testing setting, installation tools, visualization

Table 1. Material properties

No	Layer	Thicknes (h) (cm)	Density (ρ) (kg/cm)	Elasticity Modulus (E) MPA (kg/cm)	Poisson Ratio (μ)
1	Porous asphalt	5	2109	93.53 / (953.74)	0.16
2	Concrete	15	2400	26089.72 / (266041.10)	0.40
3	Clay	40	1700	62.00 / (632.22)	0.15

Examination

Set up testing, installation, and visualization tools on the pavement before the test is carried out pavement structure consists of three layers: (1) layer of soil as much as two layers with a thickness of 20 cm each solidified to obtain CBR as desired. (2) concrete slab without reinforcement layer, without any connection with a thickness of 15 cm. (3) asphalt porous with a thickness of 5 cm (Dewangan et al., 2021). Porous asphalt is spread and compacted on top of a concrete slab that had been a water-soaking binder layer (prime coat) [9]. Once the surface of the test specimen's average position then processes to install the measuring instrument linear variable differential transducer as many as six (6) units in the surface layer of porous asphalt. subsequently conducted a monotonic static loading in the middle of the pavement structure, the test object with a closed condition (assuming the side of the pavement wearing joints) (X. Wang et al., 2021). While the basic side pavement uses the spring constant. Settings loading or calibration of load cell at the time of the data logger pointed to zeros. provides loads using a hydraulic jack and load cell at a steady pace (0:02 mm / sec) on the pavement surface to obtain the maximum load.

C. Results and Discussion

Load and Deflection

This study evaluates the relationship between load and deflection on pavement structures using multilayer experimental and multilayer prediction methods. Maximum load tests were conducted on pavement structures with results shown in Table 2 and Figure 3, while simulations on SAP 2000 are presented in Figure 4.

Table 2. Deflection on pavement structure

Closed condition		
	Maximum load 126.78 Kn	
	Surface stress 2.58 (Mpa)	
	Maximum deflection (mm)	
Multilayer experimental	Multilayer prediction	Percentage difference
1	2	1 & 2
0.817	0.817	0

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From Table 2, it can be seen that the test results and multilayer predictions show the same maximum deflection value, which is 0.817 mm, at a maximum load of 126.78 kN. The agreement between the experimental test results and multilayer predictions confirms that the prediction model used is quite accurate in estimating deflection behavior in pavement structures.

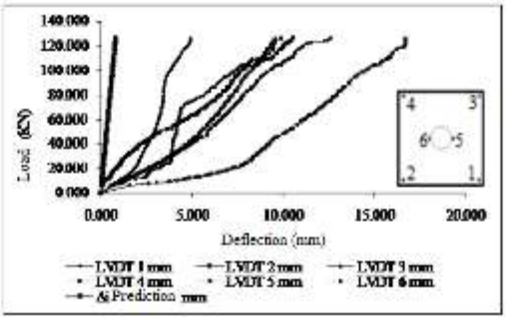

Figure 3. Relations load and deflection

Figure 3: Relationship Between Load and Deflection shows a clear linear relationship between load and deflection, indicating that the pavement structure can withstand a maximum load of 126.78 kN without sudden deflection. This condition indicates that the pavement is still within the elastic limit and has not experienced structural damage. This figure also shows the variation in the quality of the pavement structure at various load points, which are measured based on the magnitude of deflection and the angle of inclination. The smallest deflection occurs at the largest angle of inclination, and conversely, this condition describes the stiffness of the material in the road pavement layer.

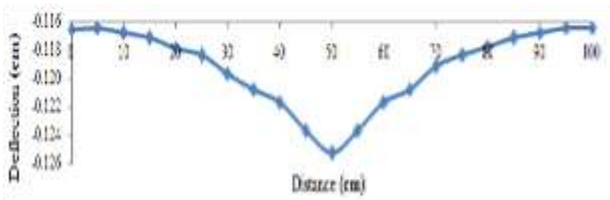

Figure 4. Deflection diagram

Figure 4 shows the deflection diagram of the pavement structure based on the SAP 2000 simulation results. This diagram illustrates the distribution of deflection evenly at various points along the pavement structure. The largest deflection is located at the load center, and the further away from the load center, the smaller the deflection. This illustrates that the load is evenly distributed throughout the pavement layer and indicates the existence of structural equilibrium under the maximum applied load.

Relationship between Load and Deflection

The results of the study indicate that there is a positive relationship between load and deflection in the pavement structure. Increasing the load causes an increase in deflection, but within the test range carried out, the resulting deflection is still within the elastic limit of the pavement material. This condition indicates that the pavement structure is able to withstand the load without experiencing permanent damage or significant performance degradation. These results also support the findings of previous studies, which state that vertical deflection in road pavements is greatly influenced by the stiffness of the material used (Dong et al., 2022). Stiffer materials tend to produce smaller deflections, which means that the pavement layer is better able to withstand loads without significant deformation (Huang et al., 2021).

Effect of Material Stiffness

Material stiffness plays an important role in determining the ability of a pavement structure to withstand loads. The relative stiffness of the material is indicated by the variation in the slope angle and the magnitude of deflection at various points along the structure. As seen in Figure 3, the smallest deflection occurs at the largest slope angle, indicating that materials with high stiffness can withstand deformation better. This is in accordance with the basic concept that material stiffness is directly correlated with the ability of the material to withstand deformation under load. In addition, the results of the study also show that the relative stiffness radius of the material affects the resulting deflection. This stiffness radius is a representation of the strength and durability of the material that is in direct contact with other pavement layers. A stiffer material will have a larger stiffness radius, which means that the resulting deflection will be smaller. Conversely, less stiff materials tend to experience greater deflection under the same load.

Effect of Contact Area and Subgrade Reaction Modulus

In addition to material stiffness, other factors such as the contact area between the load and the structure, as well as the subgrade reaction modulus, also affect the amount of deflection produced. A larger contact area will distribute the load more evenly, thereby reducing the concentration of the load at certain points and resulting in smaller deflections. The subgrade reaction modulus also plays a role in distributing the load, with stronger and more stable soils tending to produce smaller deflections in the pavement layers above them.

Validation of Multilayer Prediction Model

The similarity between the experimental results and multilayer predictions (with a difference of 0%) indicates that the prediction model used is very accurate in estimating the deflection behavior of pavement structures. This is important because a valid prediction model can be used in the planning and design of road infrastructure, to ensure that the structure built is able to withstand the load according to the desired specifications. This validation also confirms that the multilayer approach used in this study can be relied on to analyze deflection behavior on various types of pavements.

Based on the results obtained, the deflection value from the multilayer test is greater than the deflection generated from the SAP 2000 simulation, with a difference of 15.29%. This difference indicates that there is a discrepancy between the experimental deflection measurements and the numerical simulation generated by SAP 2000. However, this difference can still be considered reasonable and can be explained by several factors that affect the test results**.**

Factors Causing Differences in Deflection

(1) Real-Time Conditions in Direct Multilayer Experimental Testing, the resulting deflection is influenced by various factors such as surface roughness, variations in concrete material quality, environmental conditions (temperature, humidity), and mechanical characteristics of other pavement layers. In field conditions, some of these factors cannot be precisely controlled, which can cause experimental test results to have greater deflection than simulation results which are more ideal in nature. (2) Assumptions Used in SAP 2000 depend on certain assumptions related to material characteristics, loading, and structural restraints. These assumptions are generally ideal and do not fully represent real conditions in the field. For example, SAP 2000 assumes that the material is homogeneous and elastic, and does not consider the effects of wear, microcracks, or humidity factors that can occur in concrete during field testing. This results in simulation results having smaller deflection compared to direct multilayer test results. (3) Relative Stiffness of Concrete Pavement Layers greatly affects the amount of deflection that occurs. In multilayer tests, the materials used may have variations in stiffness, which causes larger deflections in real conditions. On the other hand, simulations in SAP 2000 do not fully capture the stiffness variations between pavement layers, so the calculated deflections may be smaller than the experimental deflections. (4) Interaction Between Concrete Layers and Subgrade is also an important factor in influencing deflection. In field tests, subgrade properties, such as soil reaction modulus, can play a major role in increasing or decreasing the deflection that occurs. In SAP 2000 simulations, these interactions may not be fully represented, especially if the subgrade model used in the simulation does not match the field conditions.

The difference in deflection of 15.29% between the results of multilayer tests and SAP 2000 simulations shows that, although numerical simulations can provide a good picture of the behavior of structures, simulation results still need to be validated with empirical data from field tests. This difference also shows that SAP 2000 cannot fully represent the real conditions faced in multilayer tests, especially in handling material variations and layer interactions. However, it is important to note that these differences are still within acceptable limits in the context of structural engineering analysis, especially when considering variables that are difficult to control under field conditions. Therefore, the SAP 2000 simulation results remain relevant and can be used as a reference for the analysis of the behavior of concrete pavement structures under maximum loads.

D. Conclusion

This study proves that the calculation of deflection using SAP 2000 can provide results that are relatively close to multilayer testing, although there is a 15.29% larger difference in experimental testing. Factors such as real-time testing conditions, assumptions used in SAP 2000, material stiffness, and the interaction of concrete layers and subgrade all contribute to this difference. Thus, the results of numerical simulations still need to be validated and supplemented with field testing to obtain more accurate and representative results.

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