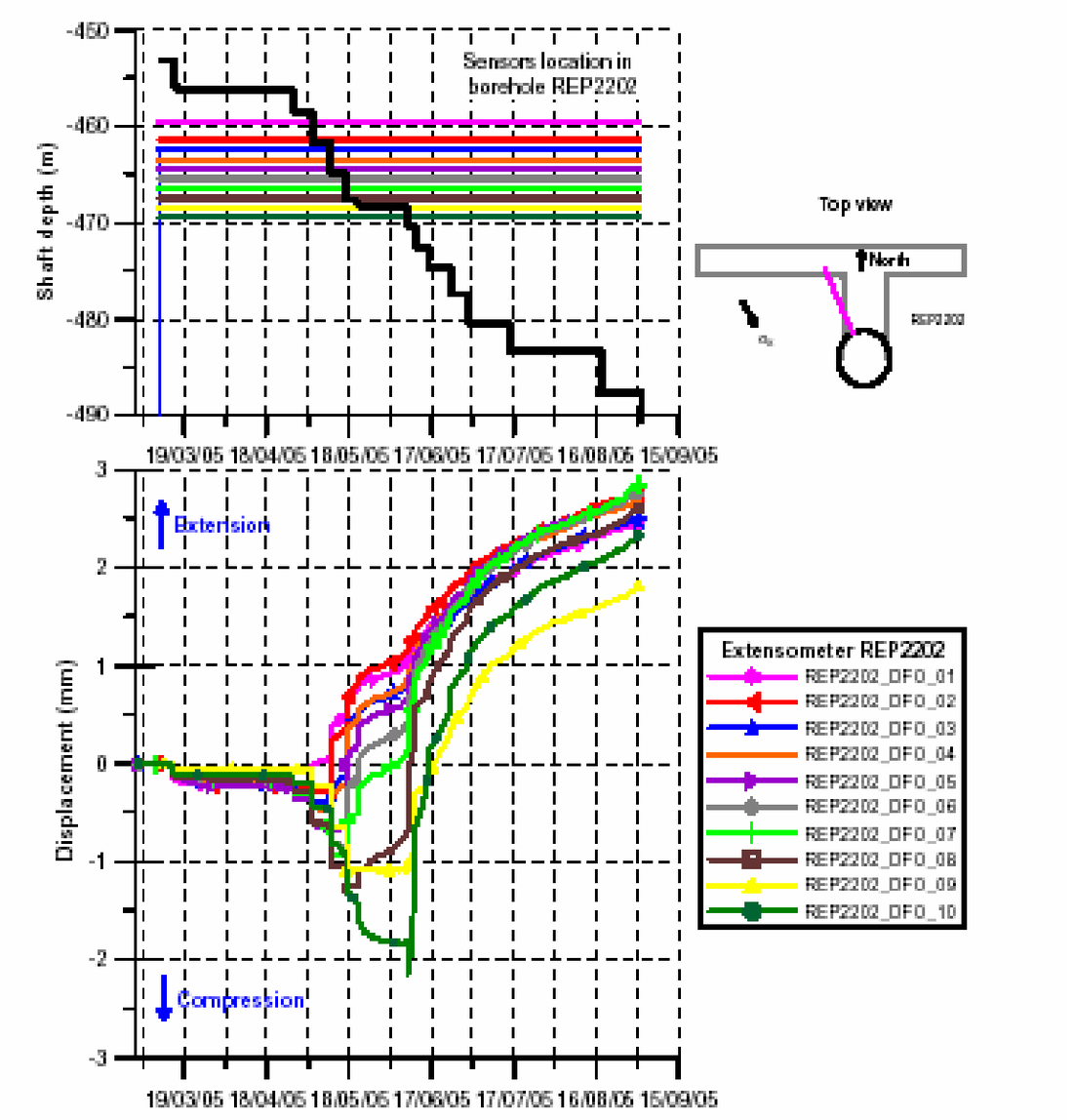

Fig. 4: Measured displacement in REP2202

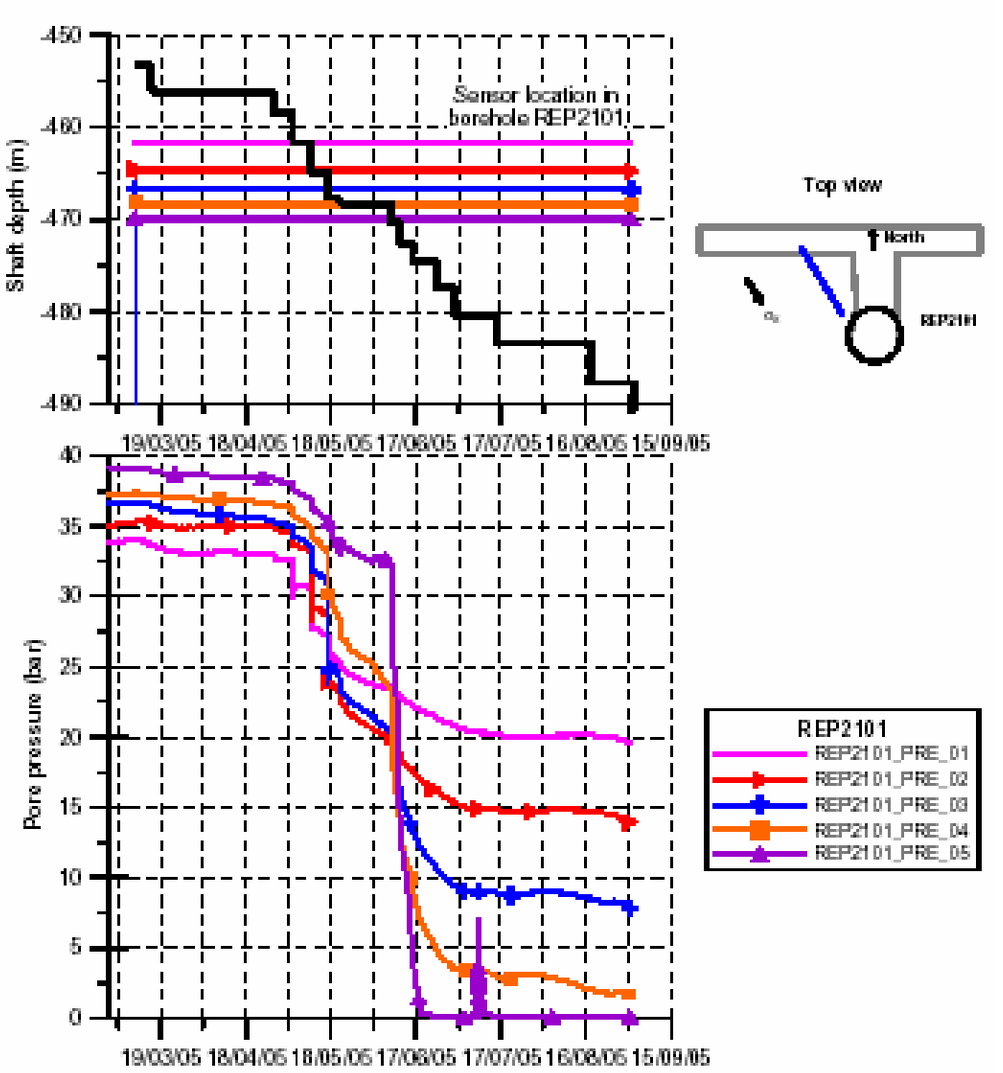

Fig. 5: Evolution of pore pressure in REP2101

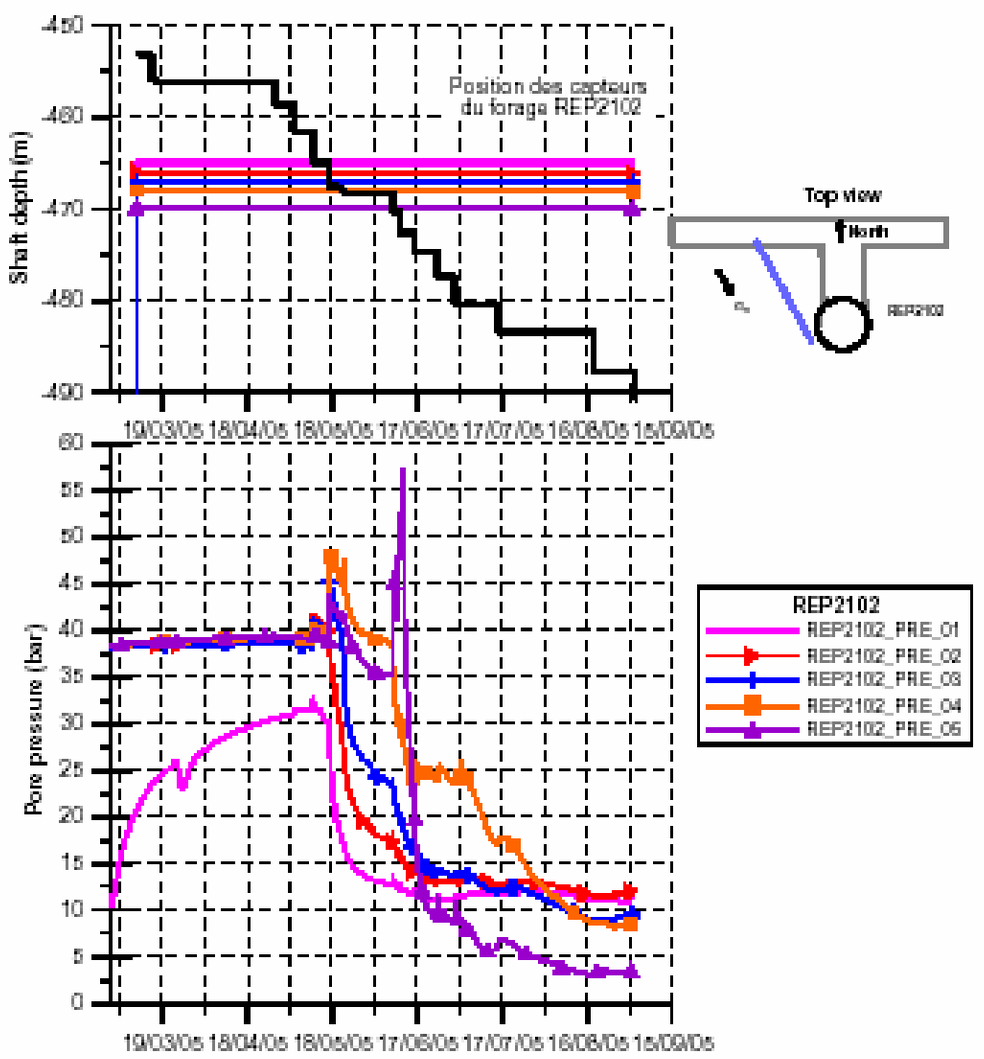

Fig. 6: Evolution of pore pressure in REP2102

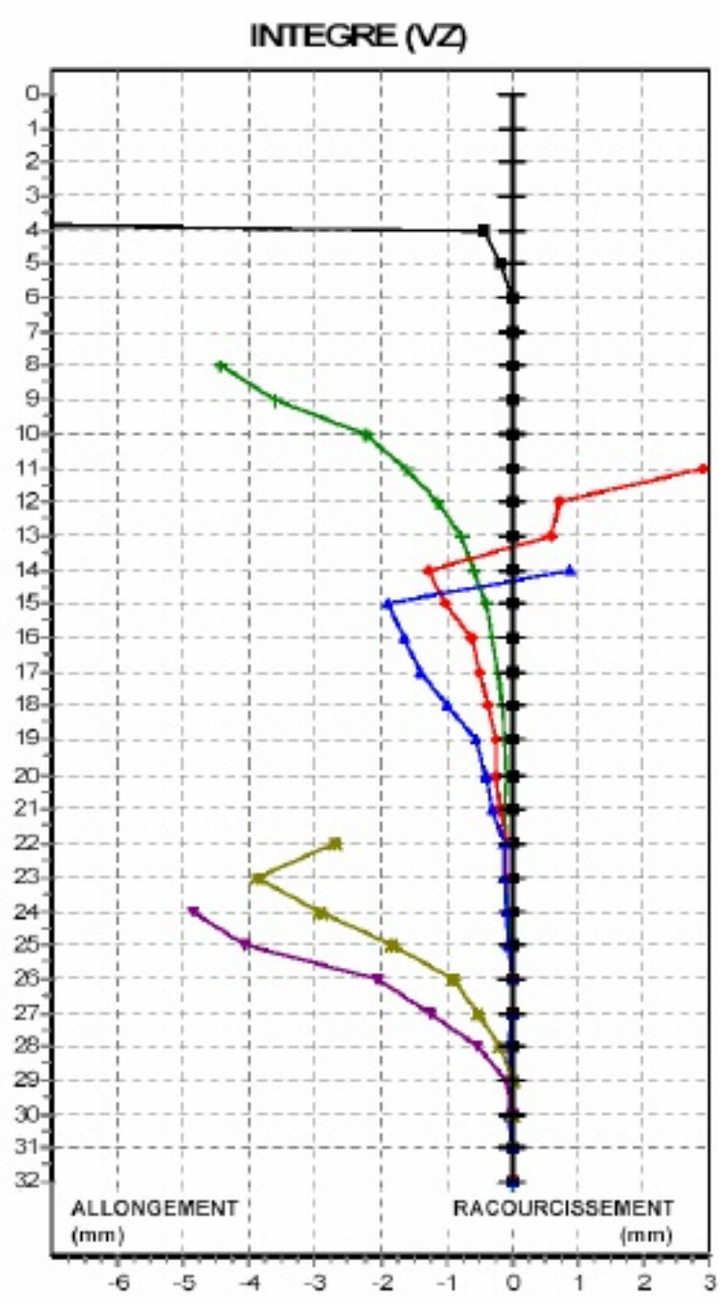

Fig. 7: Extrusion measurements in shaft axis

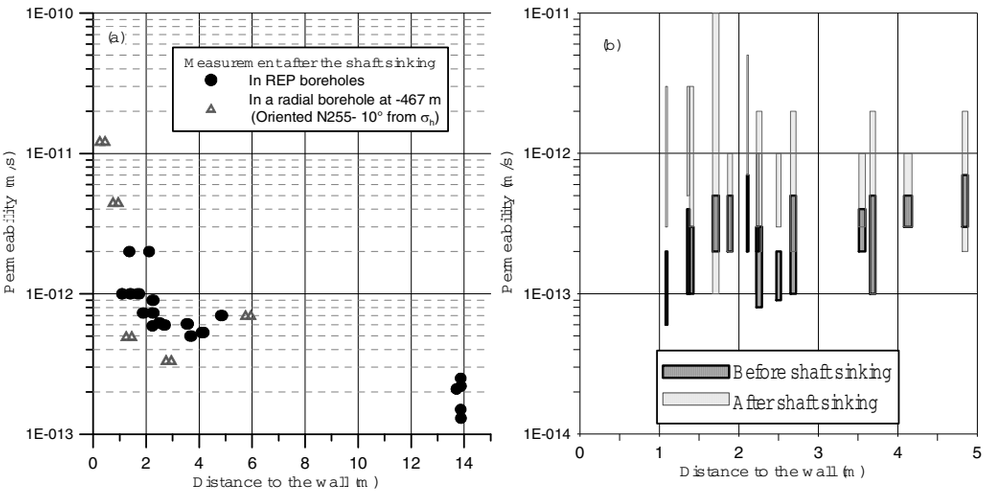

Fig. 8: Permeability measurements

5 CONCLUSION

The set of sensors installed in the framework of the REP experiment allowed us to get a large number of measurements regarding the behavior of argillites during the boring of a shaft. The PP type Multi-packer system was specifically adapted for the precise measuring of pressure variations in low permeability terrain (on the order of 10^{-14} m/s). These systems also proved their great reliability in difficult conditions.

The first results confirm a strong hydromechanical coupling, characterized by hydrostatic suppressions and subpressures generated by the boring of the shaft in a field of anisotropic stress.

These results are currently the object of modeling in the framework of the European research program, Modex-Rep.

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AUTOMATION OF THE MONITORING SYSTEM AT THE ITAIPU HYDROELECTRIC POWER PLANT

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ABSTRACT: This paper describes the various aspects upon which the Itaipu engineers based the design of a dedicated automatic data acquisition system (ADAS). It also discusses some of the technical problems that were encountered during the design and implementation and how these problems were resolved, the latter with the help of ISMES team. Mention is also given as to how the ADAS data management might be optimized in the future to become part of a dedicated system of optimization of the analysis of the *auscultation* (monitoring system) (SOAA) for (i) off-line production of periodic reports on the dam behavior, and (ii) to an on-line decision support system which continuously analyzes both manual and automated acquired data to provide an interpretation of the dam safety. Ways in which the ADAS could be integrated into a SOAA, along with data from other operating systems (such as the meteorological system and power plant production system) at the Itaipu facility, are also presented.

1. FOREWORD

The Itaipu Project was developed by ITAIPU BINACIONAL, a bi-national enterprise created in 1974 by a special treaty signed between Brazil and Paraguay for that purpose. With its 14,000 MW capacity comprised of 20 generating units, it is the largest hydroelectric development in the world.

The Itaipu Hydroelectric Power Plant is located on the Paraná River, on the border between Brazil and Paraguay. The Itaipu project consists of a series of dams of

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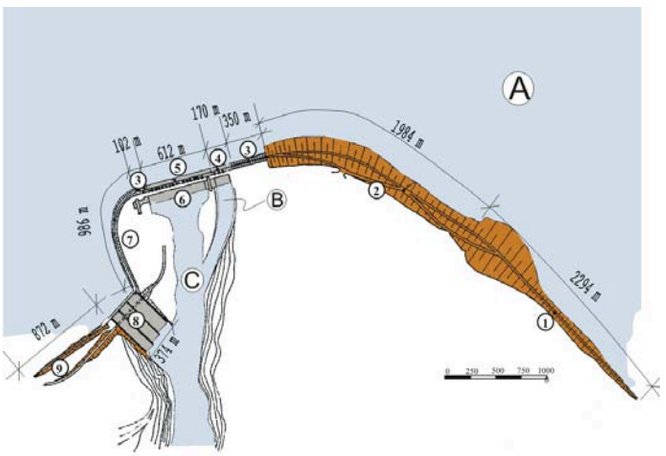
several types (a 612 m hollow gravity dam, a 170 m solid gravity dam, a 1,438 m buttress dam, a 1,984 m clay core rock fill dam, a 872m plus 2,294 m earth fill dam, and a 390 m wide gated spillway), totaling 7744m in length and with a maximum crest height of 196m. More details about the Itaipu structures and some interesting aspects of the behavior of the concrete dam and its foundations were described by Fiorini *et all* (2000).



A - Itaipu Reservoir - El. 220 m.a.s.l.
B - Downstream Level - El. 100 m.a.s.l.
C - Diversion Channel
1 - Left Earthfill Dam
2 - Rockfill Dam
3 - Left and Right Connection Dams - Buttress
4 - Diversion Structure - Massive Concrete
5 - Main Dam - Hollow Gravity Concrete
6 - Powerhouse
7 - Right Wing Dam - Buttress
8 - Right Earthfill Dam

Figure 1: General Lay-out of Itaipu Dam

The beginning of the construction was in 1975 and the impounding of the reservoir was executed in 1982.

Since the start of construction, in 1975, it was clear that a comprehensive instrumentation program would be necessary, not only to support the design of the structure itself, but also to monitor the behavior of the foundation upon which the dam is situated. As a result, a widespread monitoring plan was designed and installed. At the end of the construction period, in 1982, over 4,000 instruments had been installed and were read manually.

Thirteen years after the dam had been completed, in 1995, the number of measuring points was reduced to 2,383. On that occasion, following an in-depth analysis of the recorded data, the Itaipu Engineers carried out an exhaustive feasibility study for partial automation of the dam safety instrumentation and identified 206 instruments as being the most significant measurement points and which would, in turn, be included into a dedicated automatic data acquisition system (ADAS).

The ADAS was commissioned in December 2005 after 18 months of cooperation between Itaipu and ISMES division of Enel.Hydro actually division of CESI SpA, the Italian Company awarded the contract to provide and install it.

2. MONITORING OF THE STRUCTURES

The Itaipu auscultation system comprises close to 2,300 instruments installed in the structures and their foundations, plus close to 5,200 drains, whose data are

collected according to a pre-established frequency for each phase of the project. The analyses of the results from these instruments is complemented by routine visual inspections, or periodical, special and exceptional or emergency inspections for the purpose of detecting potential deterioration and to warn of conditions of durability that might compromise the safety of structures, since sometimes the anomalies appear in regions that are un-instrumented, where only the field inspections can detect them

A complete description of the instrumentation installed in the various blocks, the criteria adopted for the instrumentation and the quantity of instruments was presented by Cotrim et al. in 1982. The following Table 1 contains a summary of the quantities and types of the instruments installed in the structures and in their foundations:

TABLE 1 - TOTAL NUMBER AND TYPES OF INSTRUMENTS

FOUNDATION							CONCRETE									GEODETIC		Total Number	
PIEZOMETER	MULTIPLE EXTENSOMETER	TRIOTHOGONAL JOINT METER	FLOW METER	SETTLEMENT METER	NUMBER OF INSTRUMENTS	DRAIN	STRAIN GAUGE	JOINT METER	STRESS GAUGE	MOVABLE STRAIN METER	BASES OF COORDINOMETER	CRACK METER	THERMOMETER	NUMBER OF INSTRUMENTS	DRAIN	GEODETIC PRISM	BENCHMARK	TOTAL INSTRUMENTS	TOTAL DRAINS
658	**132**	**22**	**39**	**9**	**860**	**290**	**330**	**9**	**77**	**641**	**69**	**50**	**126**	**1362**	**949**	**20**	**41**	**2383**	**5239**

Geodetic surveys of the crest of the dam are carried out twice a year in order to measure the absolute vertical and horizontal displacements.

A monitoring system for seismic activity was installed before impounding the reservoir in order to detect possible earthquakes induced by the reservoir load. The system is still in operation, 25 years after the impounding of reservoir, but did not record any seismic activity which could be attributed to the influence of the Itaipu reservoir.

Some special blocks or sections, called Key-Blocks or Key-Sections, were selected to be instrumented according to their importance or peculiar conditions. A complete set of instruments was installed in these blocks.

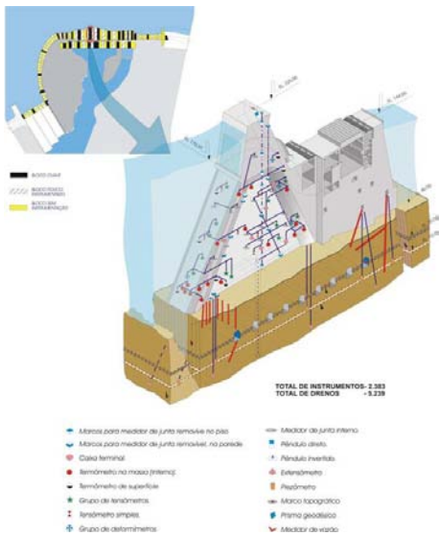


Figure 2: Dam Key Block - Instruments Location

3. OBJECTIVE OF THE ADAS (AUTOMATIC DATA ACQUISITION SYSTEM)

The main purpose of the Automatic Data Acquisition System for the Civil Instrumentation of the Dam (ADAS) is to supervise the behavior of the concrete, rock fill, and earthen dams and of their foundations, in real time, through a system of "on line" monitoring of automated instruments and sensors, with a view to acquiring the readings at the periods of frequency adjusted by the user. Various groups of sensors are connected to Remote Acquisition Units (UARs), in which the readings by the sensors will be processed, stored and transmitted to a system of treatment, storage, processing and presentation of the collected data by means of the Data Cluster and of the Client Station of the ADAS.

Major features of the ADAS can be summarized in:

- data acquisition from over 300 distinct points of measurement, related to different typologies of sensors, either represented by pre-existing instruments or by new sensors by means of the Remote Acquisition Units (herein referred with the UAR acronym)
- frequent, speedy and safe collection of data, by means of digital data transfer between the UARs and a Central Control and Processing System (herein referred with the CDA acronym), in order to assure: full remote control of peripheral apparatus, full collection of data, fast and secure alert signaling management, improvement of data processing efficiency and output information accuracy and information distribution

The ADAS system is a complex monitoring system that will enable the execution of all the operations to fulfil the main purpose described above.

Studies concerning automation of the instruments of the civil structures of the Itaipu dam, involving the viability of the automation plan, the analyses of its advantages and disadvantages, the election of instruments to be automated, etc., selected 206 instruments to integrate the ADAS, i.e., less than 10% of the total of