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VIBRATION AT BUILDINGS OF HIGH CULTURAL VALUE FROM TBM OPERATION AT ATHENS METRO LINE: AKADEMIA - SYNTAGMA

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ABSTRACT

ET&T Ltd assures, since 1993, for ATTIKO METRO S.A., a full consultancy services program concerning groundborne noise & vibration from Athens Metro construction & operation. A full monitoring & recording (M&R) program was implemented for Akademia & Iliou Melathron buildings in Akademia-Syntagma section of Athens Metro. The concept of measuring vibration always at the closest to the source (TBM cutterhead) location inside the building (worst case scenario) including the base of the statues at Akademia building front facade, and the safe at Iliou Melathron, by using a mobile M&R station with real time alarm and triggering system. In conclusion, based on the results of the monitoring program the maximum particle velocity during TBM operation at AKADEMIA and ILIOU Melathron buildings, did not exceed at any case the given criterion of DIN 4150.

1 - INTRODUCTION-RECORDING SYSTEM

ET&T has assured, since 1993, for ATTIKO METRO S.A. (*Athens Metro corporation*), a full consultancy services program concerning groundborne noise & vibration from Metro construction & operation. Within this program and during TBM (Tunnel Boring Machine) operation in the vicinity of buildings of a high cultural value, the necessity for monitoring and recording vibrations has occurred. Therefore a full monitoring & recording (M&R) program was implemented for Akademia & Iliou Melathron buildings in Akademia-Syntagma section of Athens Metro. The concept of measuring vibration always at the closest to the source (TBM cutterhead) location inside the building (worst case scenario) including the base of the statues at Akademia building front facade, and the safe at Iliou Melathron, by using a mobile M&R station with real time alarm and triggering system. The organization and execution of measurements was based on the following:

- ensuring real time monitoring & recording of the peak particle velocity time history at the nearest – to the TBM cutterhead – location of the entrance of both buildings along the excavation axis
- DIN 4150 (part 3) provisions application with constant follow up in order to avoid exceeding the relevant approved criteria
- measurements execution along each building facade during the complete TBM operation According to DIN 4150 (part 3) the max permissible values for the p.p.v. concerning buildings sensitive to vibrations are as follows:
 - Foundation: for frequencies < 10Hz at 3 mm/sec
10 – 50 Hz at 3-8 mm/sec & 50 – 100 Hz at 8 – 10 mm/sec
 - Upper floors: for all frequencies 8 mm/sec

The organization of the state of the art mobile vibration M&R station and the parameters for vibration recording were as follows:

- Vibration source: TBM operation heading to Syntagma

- Measurement parameters: Two horizontal components of the p.p.v. and one vertical i.e. 3 directions X, Y & Z using 3 sensors – computation of the p.p.v. in mm/sec at all locations in a frequency band from 1 to 100 Hz
- DAT Recorder with all recordings and/or events simultaneous recordings capabilities
- Real time monitoring system for the p.p.v. fluctuation including real time alarm and triggering system for DIN 4150 criterion monitoring
- Horizontal directions of the p.p.v.: Two WILCOXON horizontal seismic accelerometers were used with a frequency band from DC to 350 Hz (one along the tunnel axis – direction x- and two vertical to tunnel axis – direction Y)
- Vertical direction of the p.p.v.: One WILCOXON vertical seismic accelerometers was used with a frequency band from DC to 350 Hz

The signals from the accelerometers were amplified by using special amplifiers and integrated analogically in order to measure the particle velocity and then recorded in a digital TEAC DAT recorder and converted to digital using a low-pass anti aliasing filter at 100 Hz. This filtering procedure was implemented in order to avoid unpleasant aliasing phenomena during conversion to digital form. The sampling of the analog-digital converter was at 250Hz. The signal was also filtered by using a high-pass filter of 1Hz. In the same time in a computer screen all directions and p.p.v. time history was presented in real time conditions. A complete set of vibration measurements with both recording and monitoring in real time of the peak particle velocity (overall) from X, Y & Z directions at several locations in the facade and at various locations inside both buildings was executed. A state of the art Mobile M&R station was used, including for both monitoring and recording vibration from TBM operation including a DAT 9 channel recorder, 3 WILCOXON accelerometers (1-100Hz) for X, Y & Z directions, color screen, laptop for real time computation and monitoring of the P.P.V. (peak particle velocity), cables, including all necessary materials

2 - AKADEMIA BUILDING

Regarding AKADEMIA building vibration monitoring & recording was performed during the complete TBM passage from the building facade both for operation and calm periods (between end and start of each TBM operation circle) in order to evaluate all vibration fluctuations during the period from 3 to 8/11/97. Recordings of a total period of 40 hrs were taken simultaneously for all directions and computation of the p.p.v. for each time moment was executed. Simultaneously with the above measurements & recordings vibrations recordings were taken in Panapestimiou avenue above TBM cutterhead (locations TBM1 & 2). In the following figure 1, all recordings per location and date are presented.

3 - ILIOU MELATHRON BUILDING

Vibration monitoring at ILIOU Melathron building (home of the famous archaeologist Sleaman) was performed during the complete TBM passage from the building facade both for operation and calm periods (between end and start of each TBM operation circle) in order to evaluate all vibration fluctuations during the period from 19 to 21/11/97. During this operation simultaneous recordings were executed in 6 pairs of locations by using 6 sensors per pair of locations in different floors i.e. ground floor & 1st floor or ground floor & Panepistimiou str level (above TBM cutterhead) in front of the building, in order to evaluate vibration fluctuation at the same time frame in different location inside the building and evaluate vibration transmission through the soil & the building structure. Recordings of a total period of 35 hrs were taken during the M&R program simultaneously for all directions and computation of the p.p.v. for each time moment was executed using FFT analysis. From the total volume of recordings the worst case per location (with & without TBM operation) of a total period of 2,5 hrs, were saved in digital form (DAT tapes). In the following Figure 2, all recordings per pair of locations and date are presented.

Photos of the mobile M&R station used and selected measurements locations at Akademia (figs. 3, 4 and 5) & Iliou Melathron buildings (fig. 6) are presented in the end of this paper.

4 - EVALUATION OF MEASUREMENT RESULTS

- **Akademia building**: The maximum particle velocity during TBM operation is presented in diagram in figure 1. Based on the results of the monitoring program the maximum particle velocity

during TBM operation at AKADEMIA building, did not exceed at any case the given criterion of DIN 4150 (20 to 40 times lower). It was defined, that the absolute Max p.p.v recorded for all locations inside the building was 0,153241 mm/ indoor at location 8 and outdoor at location 5 at 0,179612 mm/sec. The relevant p.p.v. in the surface of Panepistimiou str. across location 9 was recorded at 0,143633 mm/sec with relevant recordings inside the building between 0,026 and 0,057 mm/sec. Relevant recordings inside the building with TBM idle but during normal Building operation (pedestrian movements at the entrance during official speech of an Akademia member) had more important magnitude than during TBM operation (0,120035 and 0,162596 mm/sec).

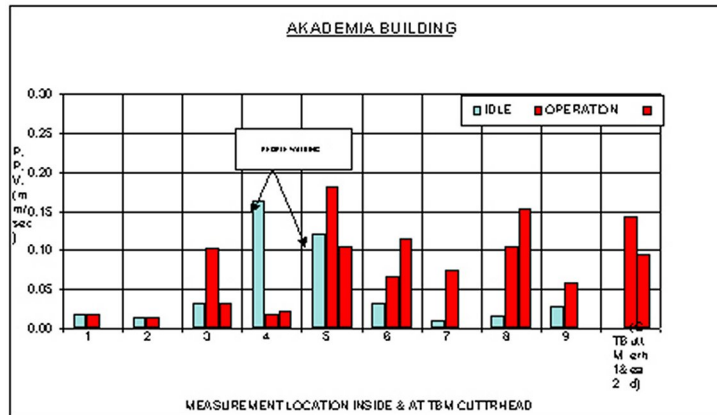


Figure 1: Diagram of the fluctuation of p.p.v. (mm/sec) for TBM idle (cyan) and in operation (red) for all locations.

- ILIOU Melathron:** The fluctuation of the worst values of p.p.v. is presented in diagram D2. Based on the results of the monitoring program the maximum particle velocity during TBM operation at ILIOU Melathron building, did not exceed at any case the given criterion of DIN 4150 (10 to 20 times lower). It was defined, that the absolute Max p.p.v recorded for all locations inside the building was 0,40 mm/ indoor at location Δ22 (1st floor). The relevant value for the p.p.v. at Panepistimiou str. across location Δ21 was recorded between **0,327 and 0,391** mm/sec with simultaneous inside the building from **0,255 to 0,29** mm/sec. Relevant recordings inside the building with TBM idle was between 0,025 and 0,04 mm/sec.

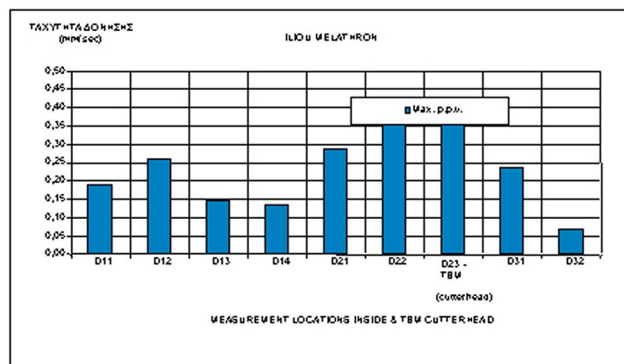


Figure 2: Diagram of the fluctuation of p.p.v. (mm/sec) for TBM operation for all locations.

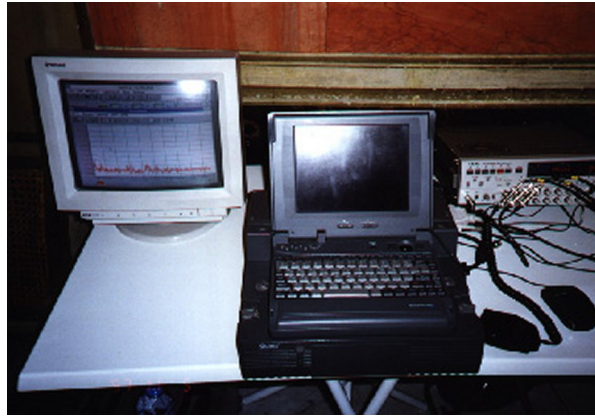


Figure 3: TBM Vibration M&R Unit.



Figure 4: Point 5/Akademia building entry.

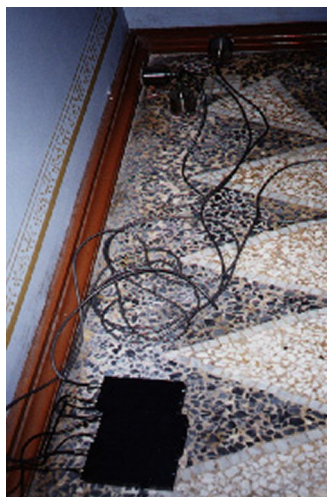


Figure 5: Point 7/N-W corner of Akademia's Library (Wilcoxon for 3 directions X, Y, Z).

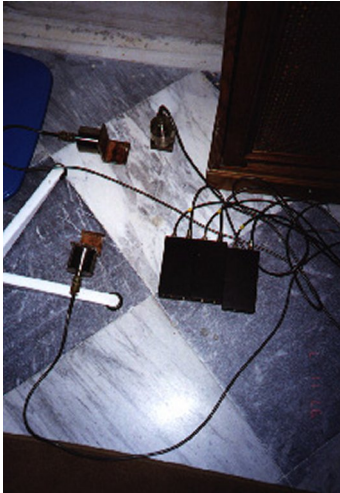


Figure 6: ILIOU Melathron -Point D1/ NW corner.