Status Report on the Long-Term Stability of the Advanced Photon Source*

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1. INTRODUCTION

The Advanced Photon Source (APS) (Fig. 1) is a third-generation synchrotron providing scientists with x-ray beams 10,000 times more brilliant than any currently available. The 7-GeV synchrotron light source produces x-rays in the soft to hard x-ray range of the electromagnetic spectrum and will be used for basic research in medicine, material science, chemistry, physics, micro-mechanics, and x-ray lithography to name some of the participating disciplines. Fully operational since 1997, the APS has about 20 sectors instrumented by various Collaborative Access Teams (CATs).

For the successful operation of an x-ray light source such as the Advanced Photon Source, the long-term stability of the concrete floor supporting the beam components and user beamlines is crucial. Settlements impact the orbit and location of the x-ray source points as well as the position of the x-ray beamlines. This paper outlines the results of successive settlement surveys of the Advanced Photon Source performed in approximately yearly intervals.

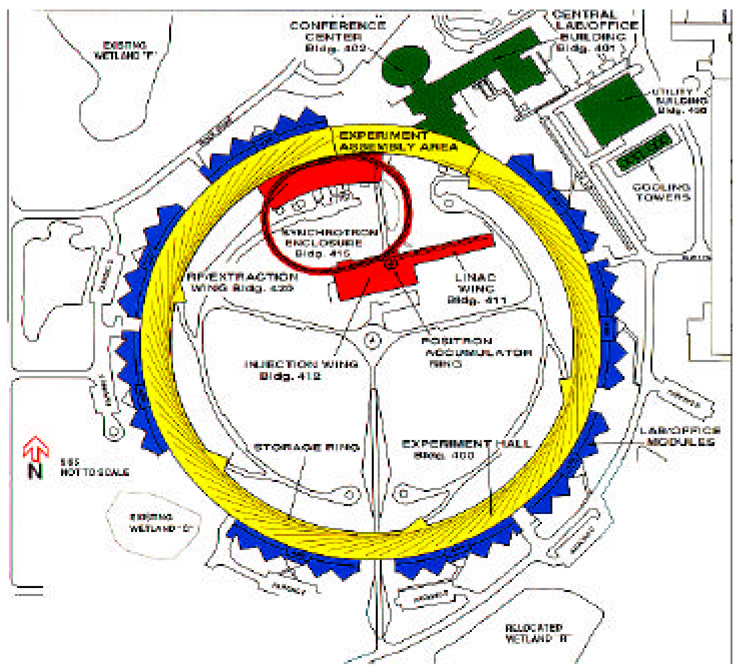

Fig. 1. APS site.

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2. LIMITING APERTURES AND SITE CONSTRUCTION

The importance of regular settlement surveys after construction of the APS was completed becomes even more apparent if one considers the smallest limiting vertical aperture in the system. Figure 2 depicts the evolution of the APS insertion device vacuum chambers (IDVCs) over time. Initially we considered installing chambers with a 12-mm vertical gap size [1]. Soon after commissioning of the APS storage ring began it became apparent that the machine would easily tolerate 8-mm vertical gap size chambers, so the production and installation of 12-mm chambers was eliminated. Today all insertion device (ID) straight sections with operational beamlines are outfitted with 8-mm ID chambers and the first 5-mm ID chamber is installed. The vertical gap of these devices was decreased to provide more powerful x-ray light to the users. This trend will continue, especially with the development of fourth-generation light sources, but it also limits the amount of settlement before these small-gap apertures prevent the particle beam from circulating in the storage ring with reasonable lifetime.

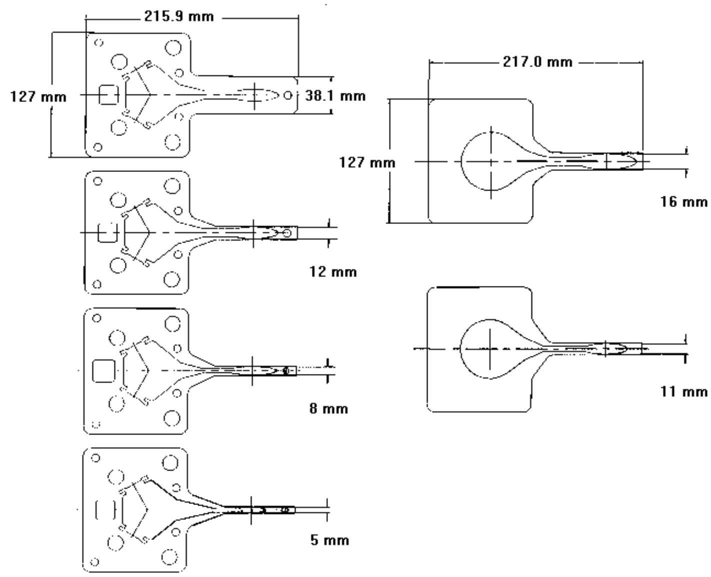

Fig. 2. APS ID vacuum chamber family.

The site selection is of utmost importance in order to ensure the long-term stability of any third-generation light source. The APS is situated at Argonne National Laboratory on highly consolidated unweathered glacial silty clay till deposited during the Pleistocene Era [2]. The occurrence of earthquakes in this area is highly unlikely and larger ground motions from other sources are not readily detectable. Only minor areas of the construction site required special preparation by removing deleterious material unsuitable for the construction of the storage ring foundation.

Unlike most other large constructions, the 1104-m-circumference storage ring/experiment hall is built on a homogeneous monolithic concrete slab supported by a contiguous rebar frame without expansion joints. This technique produces only smooth floor deformations as opposed to building the floor with many individual concrete slabs, which can produce large discontinuities at the joints. A cross section of the experiment hall/storage ring floor is shown in Figure 3. Great care was taken to ensure that the experiment hall superstructure and support utilities are maintained independently of the floor in order to minimize the effects of vibrations induced by utility pumps or heavy wind loads on the building. The concrete structure is outlined in Figure 3 in red while the support beams are shown in blue. The storage ring the floor has a thickness of about 1 m that tapers down to about 0.3 m at the outer perimeter of the experiment hall floor [1].

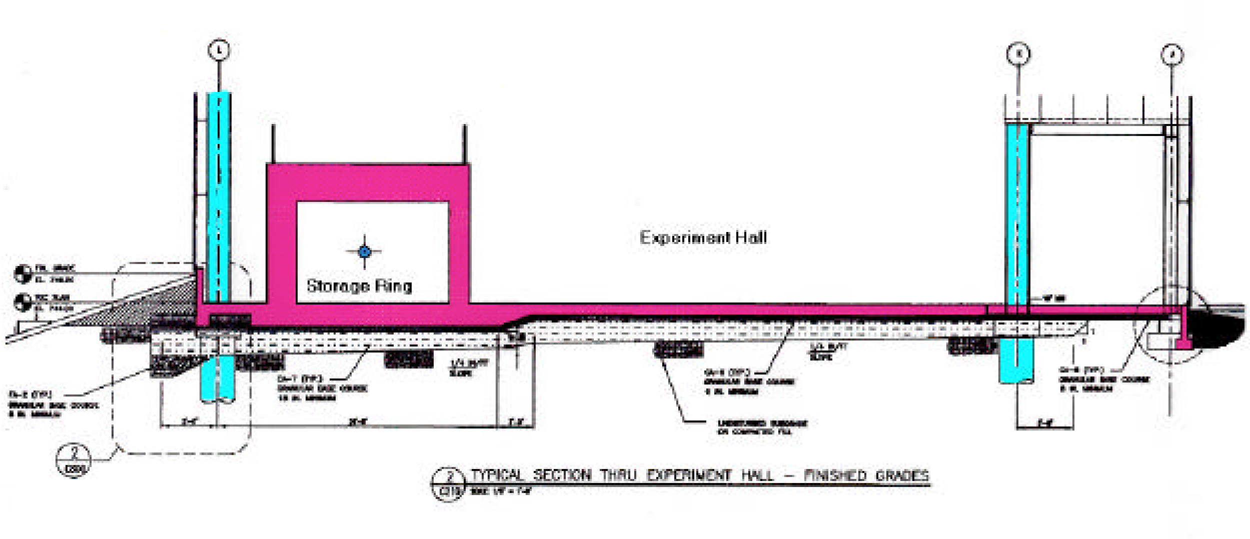

Fig. 3. Experiment hall cross section.

3. THE VERTICAL CONTROL NETWORK

The APS vertical control network consists of primary and secondary networks with a total of about 600 control points. The primary control network, depicted in Figure 4, ties the main monument located at the center of the storage ring to benchmarks strategically located near access doors into the APS building [3]. The level loops that are accessible during machine operation times are red and the loops that require tunnel access are blue. The secondary network consists of the remaining monuments located in the accelerator enclosures and that are only accessible during machine maintenance periods. The primary network is measured on a yearly basis, while the secondary network is updated approximately every six months depending on access times. The accuracy of the primary control points is on the order of ±0.1 mm, while the accuracy of the secondary control points varies between

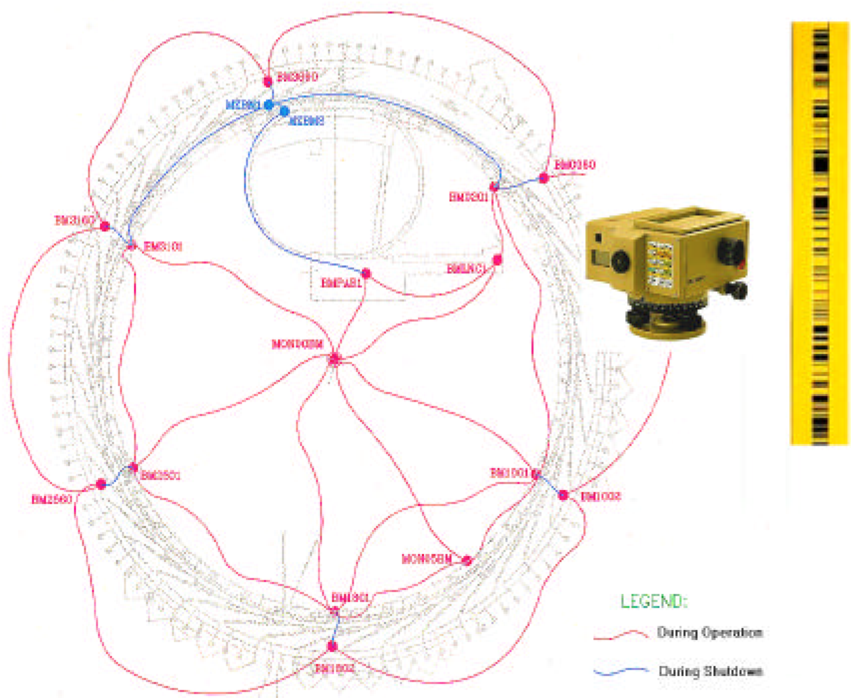

Fig. 4. APS primary vertical control network.

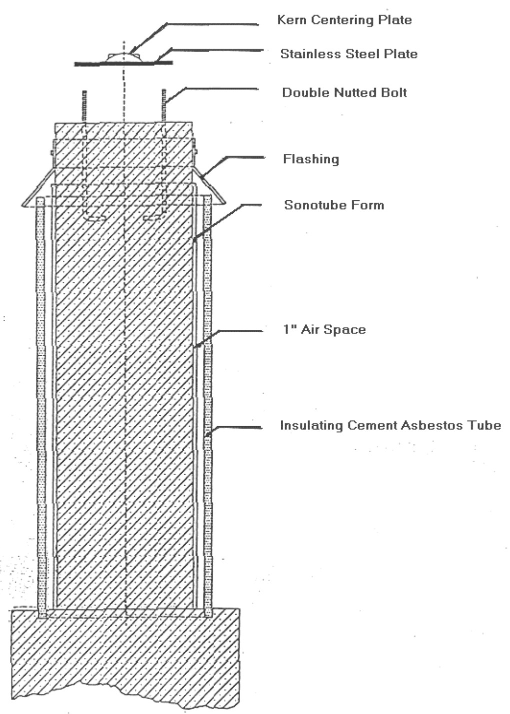

Fig. 5. APS center monument.

±0.1 mm and ±0.2 mm. The instruments used to measure the elevation network, in this case the WILD NA3000A with its associated bar-code level rod, are also shown in Figure 4.

The datum of the APS control network is defined by the elevation of the center monument, which was used during the construction phase for the layout of the accelerator housing [4]. The center monument (Fig. 5) rests atop a caisson rooted 5 m below grade. A 1.5-m-tall monument was erected above grade to provide a stable platform for a Kern centering plate. In order to prevent temperature-dependent deformations of the monument, the above-ground concrete was encased by a secondary cement asbestos tube to provide an insulating air gap between the concrete monument and the surrounding environment. Naturally, an easily accessible benchmark was attached to the monument.

4. RESULTS OF THE SETTLEMENT SURVEYS

The following figures show the results of the yearly settlement changes of the APS storage ring and experiment hall floor with respect to the 1994 datum for 1995 (Fig. 6), 1996 (Fig. 7), and 1997 (Fig. 8). Although data earlier than 1994 is available, the 1994 datum is used as the baseline because it represents the elevation status of the storage ring during installation of the beam components. Various colors and shades of color are used to represent the settlement changes derived from interpolating between the discrete measurement points. Red is used to show uplifting areas, while blue is used to show subsiding regions.

At first glance, a comparison of the figures for the three consecutive years shows that the surface roughness due to continued settlement over time has increased as indicated by the extended range of colors for each graph over time. This is also reflected in the increasing standard deviation shown in Table 1 for each of the measurement epochs.

In addition to the basic layout of the APS storage ring, key features that could cause the settlement pattern are also shown. These are the location of wetlands, distribution of the utility lines, locations of installed experiment enclosures, and zones where deleterious material had to be removed for the construction of the APS storage ring. It is apparent that there is a direct correlation between the recorded settlements and the zones where deleterious material was removed and substituted with compacted soil. In those areas the largest subsidence can be observed. The lowest

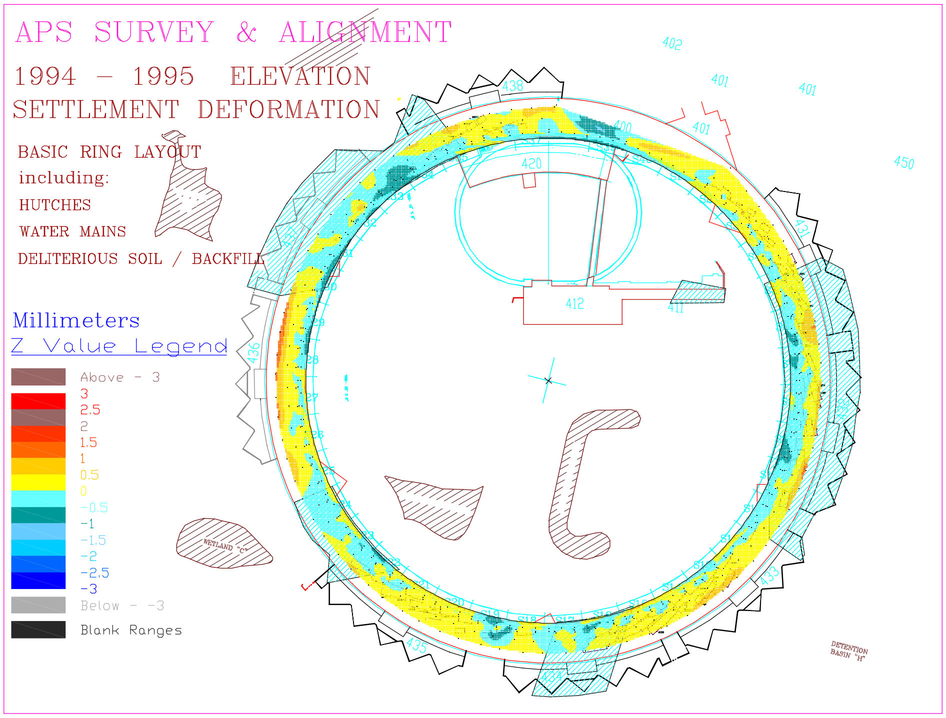

Fig. 6. Elevation changes 1994 – 1995.

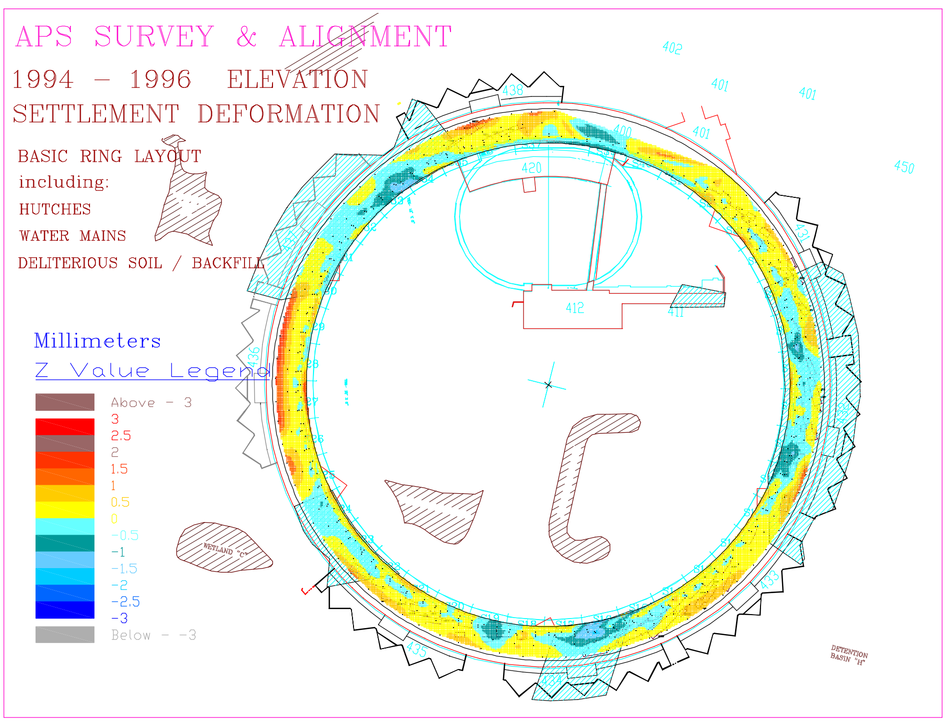

Fig. 7. Elevation changes 1994 – 1996.

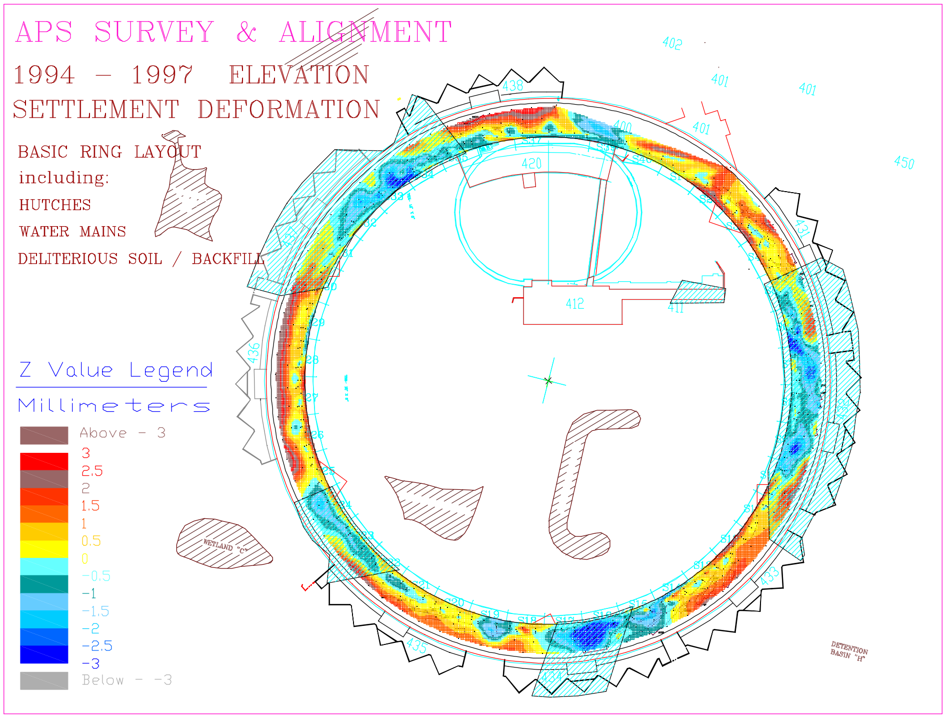

Fig. 8. Elevation changes 1994 – 1997.

point at sector 16 actually corresponds with a former wetland area that had been drained and filled with compacted soil. Control points in that area show a change of -2.4 mm for the measurement period between 1994 and 1997 resulting in a yearly rate of change of -0.8 mm.

On the other hand, areas of uplifting can mostly be observed at the outer perimeter of the experiment floor and, in one case, in the vicinity of utility lines under-cutting the storage ring and experiment hall floor at sector 2. The largest uplifting can be detected at the outer perimeter of the experiment hall floor in sectors 26 to 29. In that area the floor has changed by about +3.0 mm between 1994 and 1997 with the largest change of +1.5 mm in 1995. In comparison to other parts of the storage ring, the laboratory office modules (LOMs) outside of the experiment hall in the area of sectors 26 to 29 have not been built. One can speculate that building runoff water is not dispersed in the same way as in locations where LOMs have been erected and may therefore be the cause for uplifting in that section due to hydostatic pressure.

5. SUMMARY

Table 1 summarizes the average elevation changes and standard deviations as well as the points with the largest changes for each year. On average, hardly any settlements can be detected; however, local changes of +2.90 mm to -2.31 mm have been measured. Looking at the low and high points, the settlement process is slowing down over time. Overall, the settlements observed match the expectations for this type of construction.

Table 1. Elevation changes summary

	Point name	1995	1996	1997
High point	S2970	1.61 mm	2.20 mm	2.90 mm
Low point	S1630	-0.73 mm	-1.68 mm	-2.31 mm
Average change		0.003 mm	0.050 mm	0.023 mm
Standard dev.		0.342 mm	0.487 mm	0.652 mm

To date no major realignment of the APS storage ring has been necessary. The particle beam tracks with the settlements of the floor as long as these changes occur in a smooth fashion and not as sudden discontinuities [5]. From Figures 6 through 8 it is also apparent that settlements affect larger areas in the storage ring and experiment hall that impact the location of the source point as well as the location of the beamline user equipment.

The limiting apertures of the insertion device chambers will make realignment of the APS storage ring a necessity at some point in the future. Currently simulations and machine studies are underway to provide an estimate of tolerable settlement limits before a realignment of certain sections of the storage ring would be required.

In conclusion, the APS has been constructed on solid ground with an excellent foundation. Only small settlement changes are being observed; so far they are not impacting the operation of the accelerator. We are continuing to monitor deformations of the APS floor in anticipation of a future realignment of the accelerator components.

6. ACKNOWLEDGMENTS

Finally, I would like to acknowledge all APS survey personnel for their effort in the maintenance of the APS. Especially I would like to thank M. Penicka for the data analysis and J. Error for producing the graphs showing the results of the settlement surveys.

7. REFERENCES

[1] 7-GeV Advanced Photon Source Conceptual Design Report, Argonne National Laboratory, ANL-87-15, 1987.

[2] Geotechnical Report from STS Consultants Ltd., *Title II Subsurface Exploration and Geotechnical Engineering Evaluation for the Proposed 7-GeV Advanced Photon Source*, Volume I and II, April 1990.

[3] H. Friedsam, *The Alignment of the Advanced Photon Source at Argonne National Laboratory*, Proceedings of the Third International Workshop on Accelerator Alignment, Annecy, France, September 1993.

[4] H. Friedsam, J. Penicka, S. Zhao, *Survey and Alignment Report on the Primary Control Network for the APS*, Light Source Note LS-220, 1993.

[5] H. Friedsam, M. Penicka, S. Zhao, *Beamline Smoothing of the Advanced Photon Source*, Proceedings of the 1995 Particle Accelerator Conference, Dallas, USA, March 1995.