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Investigation of Soft Stories in Buildings with Hollow Block Slab

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Abstract

Hollow block slab is a floor slab system that consists of a thin slab and joists. In hollow block slab system, nonstructural materials are used between joists. Hollow block slab usually consists of wide and shallow beams. Because of low beam height in this system, its lateral stiffness is less than beam floor systems. Because hollow block slab has low lateral stiffness, using of this slab type increases soft-story risk in buildings that have soft-story risk. Therefore, in building with hollow block slab should be detailedly investigated regarding soft-story. For this reason, in this study buildings with stores of 5, 8 and 11, which constructed with hollow block slab were numerically investigated for different ground story height. According to analysis, lateral drift ratios was obtained for each story. As ground story height increased, the lateral drift ratios of ground story with hollow block slab were increased nearly between 33% and 50%. As the number of stories increased, the lateral drift ratios have approached upper limit which is recommended by TEC-2007. The high values of lateral drift ratios in ground stories increase soft-story risk. This situation has a negative effect on building performance under lateral loads. For improving this negative effect shear walls was added to the systems and analysis was repeated. Because shear walls have decreased lateral drift ratios of ground stories nearly between 40% and 60%, negative effect of increment in ground story was decreased. It is agreed on that in high seismic zone, buildings with hollow block slab should be designed as a frame-wall system for better building performance.

Keywords: Hollow block slab, Soft-story, Lateral drift ratio, Reinforced concrete building

Asmolen Döşeme Sistemli Binalarda Yumuşak Kat Düzensizliğinin İncelenmesi

Özet

Asmolen döşeme sistemi ince bir plak tabakası ve dişlerden oluşan döşeme sistemidir. Asmolen döşeme sisteminde, dişlerin arası taşıyıcı özelliği bulunmayan dolgu malzemesi ile doldurulur. Asmolen döşeme sistemi genellikle geniş ve sığ kirişlerden oluşmaktadır. Sığ kiriş yüksekliğinden dolayı, bu sistemlerin yatay ötelenme rijitlikleri kirişli plak döşemeli sistemlere oranla düşüktür. Asmolen döşeme sistemi, düşük yatay ötelenme rijitliğine sahip olmasından dolayı, yumuşak kat düzensizliği riski bulunan binalarda, bu döşeme tipinin kullanılması yumuşak kat düzensizliği riskini arttıracaktır. Bundan dolayı, asmolen döşeme sistemine sahip binalar yumuşak kat düzensizliği açısından detaylı bir biçimde incelenmelidir. Bu amaçla, bu çalışmada asmolen döşeme sistemli 5, 8 ve 11 katlı binalar, farklı zemin kat yükseklikleri için sayısal yöntem kullanılarak incelenmiştir. Analizler neticesinde, her kat için göreli kat ötelenme değerleri elde edilmiştir. Zemin kat yüksekliği arttıkça, asmolen döşeme sistemli yapıların zemin katında oluşan göreli kat ötelenmelerinin yaklaşık %33 ile %50 arasında arttığı tespit edilmiştir. Kat sayısı arttıkça, zemin kattaki ötelenmelerin artarak TDY-2007 tarafından önerilen üst sınıra yaklaştığı görülmüştür. Zemin kattaki yüksek göreli kat ötelenmeleri, yumuşak kat düzensizliği riskini arttırmaktadır. Bu durum yatay yükler altında binanın deprem performansını olumsuz etkilemektedir. Bu sakıncalı durumu düzeltmek için betonarme perdeler sistemlere eklenmiş ve analizler tekrarlanmıştır. Betonarme perdelerin, binaların zemin katında oluşan göreli kat ötelenme değerlerini yaklaşık %40 ile %60 arasında azaltarak, zemin kat yüksekliğinin artmasından kaynaklanan olumsuz durumun etkisini azalttığı görülmüştür. Asmolen döşeme sistemine sahip binaların, deprem tehlikesinin yüksek olduğu bölgelerde güvenli bir şekilde tasarımının yapılması için, perde-çerçeve sistem olarak tasarlanmasının uygun olduğu görülmüştür.

Anahtar kelimler: Asmolen döşeme sistemi, Yumuşak kat düzensizliği, Göreli kat ötelenmesi, Betonarme bina

1. Introduction

Hollow block slab is a floor slab system that consists of a thin slab and joists. There are nonstructural materials between joists. Hollow block slab provides important advantages such as effective using of story height and interior design in buildings for architects. Furthermore, hollow block slab that has a flat slab ceiling reduce formwork and construction time. Because of these advantages, the using of this type slabs have become more common.

Hollow block slab usually consists of wide and shallow beams for providing a flat slab ceiling. The height of hollow block slab is determined compatible with nonstructural materials (styrofoam, briquette, tile) that use between joists. In Turkey, the thickness of the hollow block slab is usually 300 mm or 320 mm [1]. Because of low beam height in this system, its lateral stiffness is less than beam floor systems. Because hollow block slab has low lateral stiffness, lateral drift ratio in this system may be more under lateral loads, and this system may show weak performance under earthquake load.

In Turkey, the ground story of buildings that is existed two sides of main streets is used as commercial areas. For this reason, the height of this story is more than other stories and infill walls that are existed in upper stories between frames partly or completely remove in ground story. Recent years, in this building, using of hollow block slab system have become more common for using story height effectively and for providing a flat slab ceiling. This situation reduces the lateral stiffness of buildings especially in ground story and increase the risk of soft-story. This situation has a risk for buildings in Turkey where has earthquake zones. In Turkey, the soft-story effect is one of the main reason of damage sustained by reinforced concrete buildings during earthquakes [2, 3]. After Van Earthquake (2011), it was reported that soft story was the most common irregularity in collapsed buildings [4].

In this study, soft-story in building with hollow block slab was numerically investigated for different ground story height. For numerically studys 5, 8, 11 stories buildings that are used commonly in Turkey were investigated. Structure analysis software SAP2000 and IdeCAD was used for analysis [5, 6]. According to analysis, lateral drift ratios was obtained for each story. It is shown that as ground story height increased, the lateral drift ratios of buildings have reached limits that have negative effects on building performance under earthquake load. For restricting lateral drift ratios and improving building performance under earthquake load, shear walls added to the system and analysis was repeated. It is shown that because shear walls restrict lateral drift ratios of ground story, the earthquake performance of the building is improved.

2. The Earthquake Performance of Building with Hollow Block Slab

Over three decades, because of advantages of hollow block slab have been commonly used in Middle East countries including Turkey [7]. Because there is not enough experimental and numerical study that investigate the performance of hollow block slab under lateral loads, the performance of this system under earthquake loads doesn't know as much as beam floor systems. Because there is not enough experimental study that investigates the performance of hollow block slab under earthquake loads, most country's earthquake codes prevent using this system in seismic regions or allow with some requirement about dimensions or spacing of reinforcement using this system in seismic regions [8, 9].

Figure 1. A building with hollow block slab

Hollow block slab (Figure 1) usually consists of wide and shallow beams. Because of low beam height in this system, its lateral stiffness is low. Because hollow block slab has low drift stiffness, this system may have more lateral drift ratio under lateral loads. In the building, more lateral drift ratios may cause more second order effect. This situation has a negative effect on building performance under earthquake loads. For example, in 2011 Van Earthquake, it is shown that damage of infill walls in building with hollow block slab are more than beam floor system. The reason is that hollow block slab that has shallow beam can't restrict the rotation at the end of the column at enough level under lateral loads, and big lateral drift ratios happen in building [10].

Figure 2. A damaged building with hollow block slab after Van Earthquake (2011)

Hollow block slab, because of weak performance has been restricted by Turkey Earthquake Code (TEC). TEC-1975 allows using this system in a seismic zone with a requirement which buildings higher than certain height must have shear walls [11]. TEC-1998 and TEC-2007 allow using of hollow block slab in high seismic zones only if structural elements (column, beam and beam-column joints) are designed ductile, if the structural elements are not ductile, shear walls have to be used in the system [12, 13]. But, in existing buildings with hollow block slab, TEC requirements are neglected, and buildings with largely weak performance under earthquake loads have been built. The most important proof of this situation is that these type buildings were heavily damaged in Bingöl Earthquake (2003) [2]. Figure 2 shows damaged building with hollow block slab after Van Earthquake (2011).

3. Soft-Story Effect

In Turkey, the ground story of buildings that exist two sides of main streets is used as commercial areas. For this reason, the height of this story is more than other stories. Furthermore, infill walls that exist in the upper story between frames partly or completely remove in ground story. In this situation, in the ground story that has big earthquake loads, lateral stiffness of building is decreased, and because of lateral drift ratio, the building experiences degradation of strength. Furthermore, recent years, in these buildings, using of hollow block slab have become more common for using story height effectively and for providing a flat slab ceiling. Authors think that in these type buildings, the using of hollow block slab reduces the performance of building under earthquake loads.

Designing of the ground story with more height than upper story and removing of infill walls of the ground story have negative effects on reinforced concrete (RC) building performance under earthquake load. Because infill walls restrict lateral drift ratios of the building, infill walls increase the load carrying capacity of the building. For example, under Lorca earthquake, a research investigates performance of RC buildings with one-way slabs with wide beams, for buildings, three wall densities are considered: no walls, low wall density, and high wall density. Results show that infill walls increase the lateral stiffness of buildings and decrease lateral drift ratios of buildings under earthquake loads [14]. Especially, because infill walls that exist in the upper story between frames partly or completely remove in ground story, ground story have more lateral drift ratio than the upper story. Past studies show that if infill walls of the ground story are removed, the lateral load carrying capacities of building reduce 30% and the maximum lateral drift ratios of building increase 10% [3, 15]. Although TEC-2007 in the design of reinforced concrete building considers the weight of infill walls, it neglects the effect of infill walls on frame system [13]. The real performances of the buildings can't be calculated due to this negligence. For this reason, they think that design of these type buildings should be detailedly investigated. Authors are planning a long-term study that considers the effect of infill walls on the building.

4. Numerical Study

In this study, soft-story in buildings with hollow block slab was numerically investigated for different ground story height. For numerical analysis 5, 8 and 11 stories square floor plan of buildings was investigated. Figure 3 show the typical square floor plan of buildings. According to common using heights of the first floor was determined for 3.0m, 3.5m, 4.0m, 4.5m. Except for height of ground story, all heights of stories are 3.0m.

In hollow block slab, the dimension of joists was chosen as 150/320 mm and the dimension of the slab as 70 mm. The nonstructural material was chosen as styrofoam. For providing a flat slab ceiling, heights of all beams of frames was chosen as 320 mm, and for providing enough stiffness, wide of all beams was chosen as 600 mm. Material properties were chosen 25 MPa for concrete compressive strength and 420 MPa yield strength for steel.

Buildings were designed minimum requirement accordance with TEC-2007 and TS-500 (*Turkish Building Code*) [13, 16]. Buildings were designed for first earthquake zone and Z3 soil class. Dimensions of the column in a building stayed unchanged so that only effect of changing of ground story height is investigated. Table 1 shows the dimension of columns and beams.

For linear analysis of designed buildings, structure analysis software SAP2000 and IdeCAD was used for analysis [5, 6]. According to analysis, lateral drift ratios was obtained for each story. Two different softwares, in these sensitive systems, were considered for investigating accuracy rating of software. According to analysis, lateral drift ratios were obtained for each story. For the different height of the ground story, changing of obtained lateral drift ratios have been presented in tables and graphics. The lateral drift ratios that were obtained from structure analysis software IdeCAD have been shown in graphics (Figure 4-9). The lateral drift ratios that were obtained from structure analysis software SAP2000 have been presented in tables (show in Table 2). The limited number of paper influences this presentation.

According to analyses result in a frame system, as ground story height increased, the lateral drift ratios became more. For designing safety building against to earthquake, TEC-2007 state that 2% is limit of the lateral drift ratios [13]. But it is shown that as the number of stories increased, the lateral drift ratios have approached limits and the lateral drift ratios of 11 stories building have reached 2% (this can be seen in Table 2). This increment increases the risk of soft-story.

Table 1. Dimensions of columns and beams(mm)

	Dimensions of Columns		Dimensions of Beams
	Inside	*Outside*	
5 stories	450/450	450/450	600/320
8 stories	500/500	450/450	600/320
11 stories	550/550	500/500	600/320

For reducing the lateral drift ratios, in the both direction in systems, as much as 1% of the area plan, shear walls added to system and analysis was repeated. In both direction, four shear walls that have 30/210 dimension symmetrically added to the system. It is shown that shear walls have considerably reduced the lateral drift ratios and have reduced negative effects from the increment of ground story height. It is shown that in the frame-wall system, lateral drift ratios have reached maximum 1.4%. Because shear walls have decreased lateral drift ratios of ground stories, negative effect of increment in ground story was decreased.

5. Conclusion

In this study, lateral drift ratios of buildings with hollow block slab under earthquake loads was numerically investigated regarding the effect of the ground story height on lateral drift ratios.

For numerically study, lateral drift ratios of 5, 8, 11 story RC buildings was obtained. According to analyses;

- For frame structures, it is shown that when the height of ground story increased from 3.0m to 4.5m, lateral drift ratios of ground story increased nearly 50%.
- As the number of stories increased, the lateral drift ratios approach upper limit 2% which is recommended by TEC-2007. For 11 stories buildings, drift ratios that are obtained

from using structure software SAP2000 reached this limit.

The effect of infill walls was not considered for this study. In case infill walls which are usually used for design are removed in ground story, it is thought that the increasing in lateral drift ratios will exceed the limit 2% value. Because TEC-2007 don't consider the effect of infill walls on the frame in design, the risk of soft-story is high in these type buildings. For preventing the risk of soft-story, shear walls should be added the systems. It is shown that shear walls reduce the lateral drift ratios of 5 stories buildings on average 65%, 8 stories buildings on average 55%, 11 stories buildings on average 45%. In the frame-wall system, lateral drift ratios reached maximum 1.4%.

Because hollow block slab has low lateral stiffness, it shows weak performance under earthquake loads. This type slabs in the high seismic zone should be carefully designed as a frame-wall system. Furthermore, lateral drift ratios in hollow block slab should be investigated with the effect of infill walls on the building.

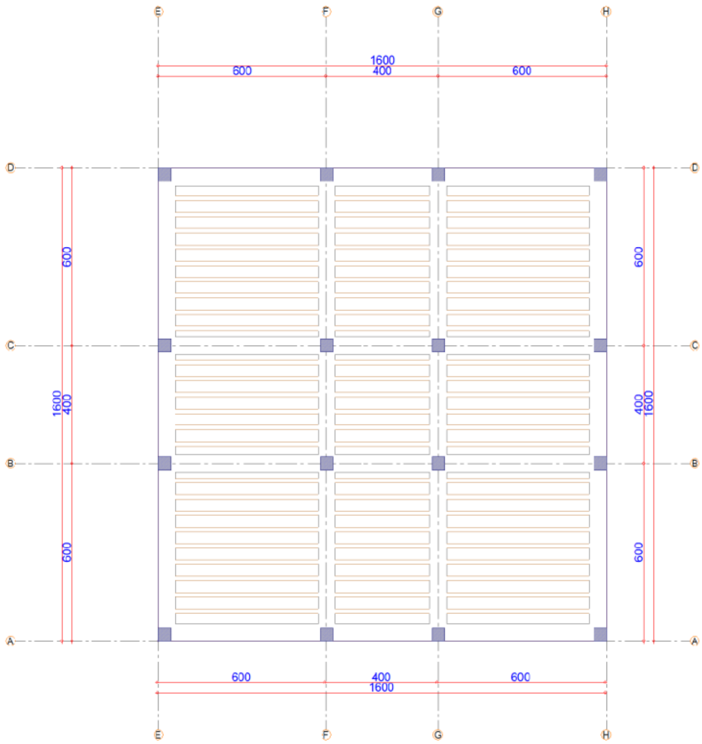

Figure 3. Square floor plan of a building

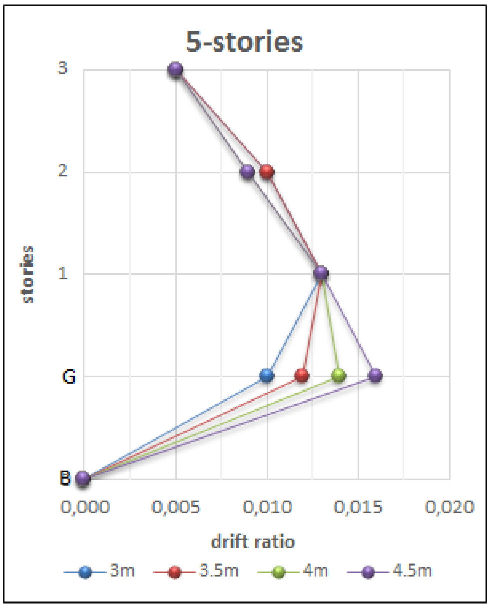

Figure 4. Frame structure with story of 5

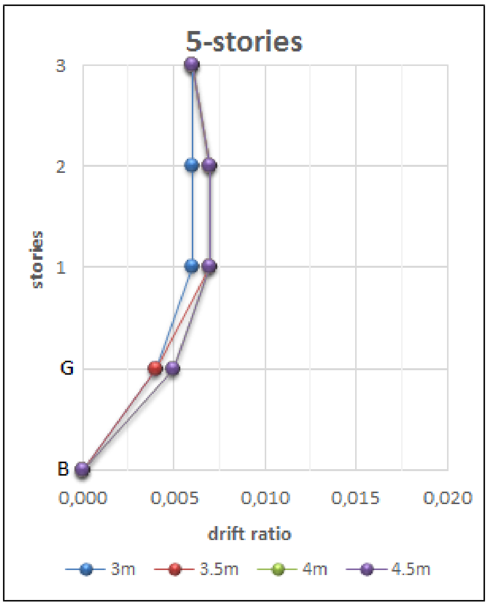

Figure 5. Frame-wall structure with story of 5

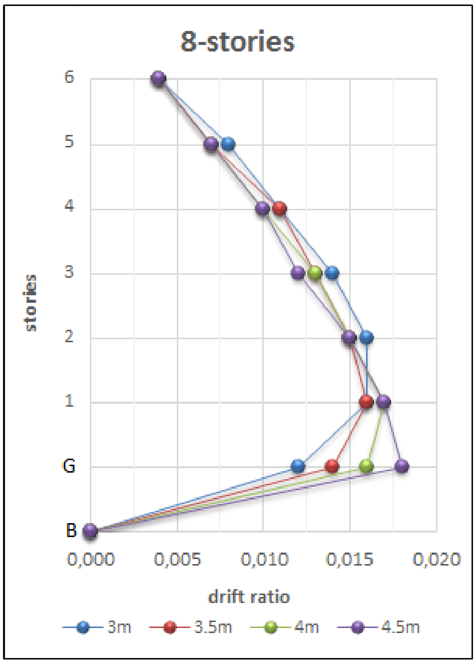

Figure 6. Frame structure with story of 8

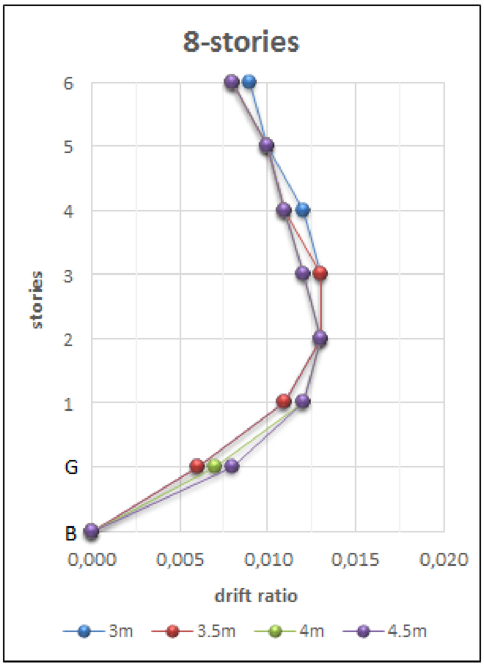

Figure 7. Frame-wall structure with story of 8

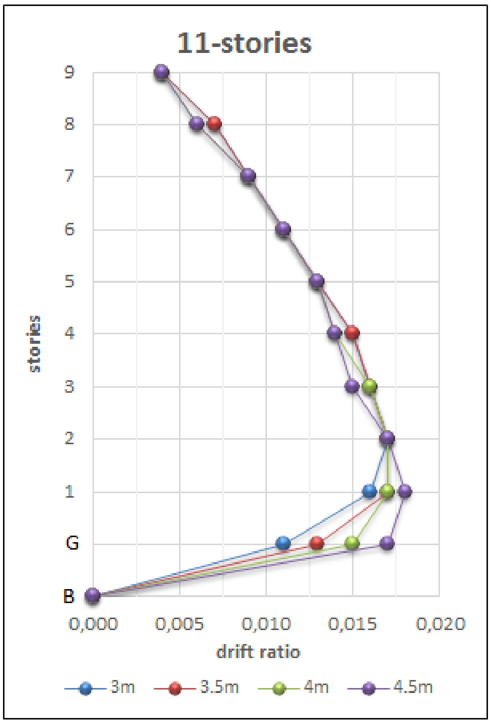

Figure 8. Frame structure with story of 11

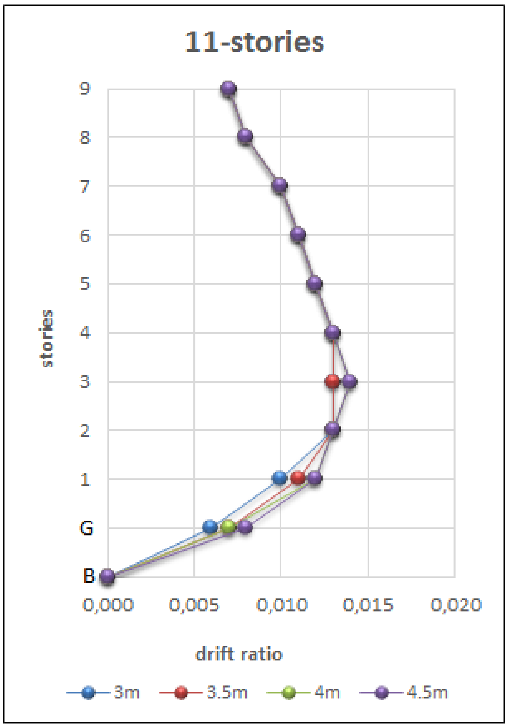

Figure 9. Frame-wall structure with story of 11

Table 2. Lateral drift ratios of buildings from sap2000

5 Stories frame structure											
Ground story H (m)	B	G	1	2	3						
3	0.000	0.010	0.014	0.010	0.006						
3.5	0.000	0.012	0.014	0.010	0.005						
4	0.000	0.014	0.014	0.009	0.005						
4.5	0.000	0.016	0.013	0.009	0.005						
5 Stories frame-wall structure											
Ground story H (m)	B	G	1	2	3						
3	0.000	0.003	0.005	0.005	0.005						
3.5	0.000	0.003	0.005	0.006	0.005						
4	0.000	0.004	0.006	0.006	0.005						
4.5	0.000	0.004	0.006	0.006	0.006						
8 Stories frame structure											
Ground story H (m)	B	G	1	2	3	4	5	6			
3	0.000	0.012	0.017	0.016	0.014	0.011	0.007	0.004			
3.5	0.000	0.014	0.017	0.016	0.013	0.011	0.007	0.004			
4	0.000	0.016	0.017	0.015	0.013	0.010	0.007	0.004			
4.5	0.000	0.018	0.018	0.015	0.013	0.010	0.007	0.004			
8 Stories frame-wall structure											
Ground story H (m)	B	G	1	2	3	4	5	6			
3	0.000	0.005	0.009	0.01	0.01	0.009	0.008	0.007			
3.5	0.000	0.005	0.009	0.01	0.01	0.009	0.008	0.007			
4	0.000	0.006	0.01	0.011	0.01	0.009	0.008	0.007			
4.5	0.000	0.006	0.01	0.011	0.01	0.009	0.008	0.007			
11 Stories Frame Structure											
Ground story H (m)	B	G	1	2	3	4	5	6	7	8	9
3	0.000	0.012	0.019	0.02	0.018	0.017	0.015	0.012	0.01	0.007	0.004
3.5	0.000	0.014	0.019	0.02	0.018	0.017	0.014	0.012	0.01	0.007	0.004
4	0.000	0.016	0.02	0.02	0.018	0.016	0.014	0.012	0.009	0.007	0.004
4.5	0.000	0.018	0.021	0.019	0.018	0.016	0.014	0.012	0.009	0.006	0.004
11 Stories frame-wall structure											

Ground story H (m)	B	G	1	2	3	4	5	6	7	8	9
3	0.000	0.006	0.01	0.012	0.013	0.013	0.012	0.011	0.009	0.008	0.006
3.5	0.000	0.006	0.011	0.013	0.013	0.013	0.012	0.011	0.009	0.008	0.006
4	0.000	0.007	0.011	0.013	0.013	0.013	0.012	0.01	0.009	0.007	0.006
4.5	0.000	0.007	0.012	0.013	0.013	0.013	0.012	0.011	0.009	0.008	0.006

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